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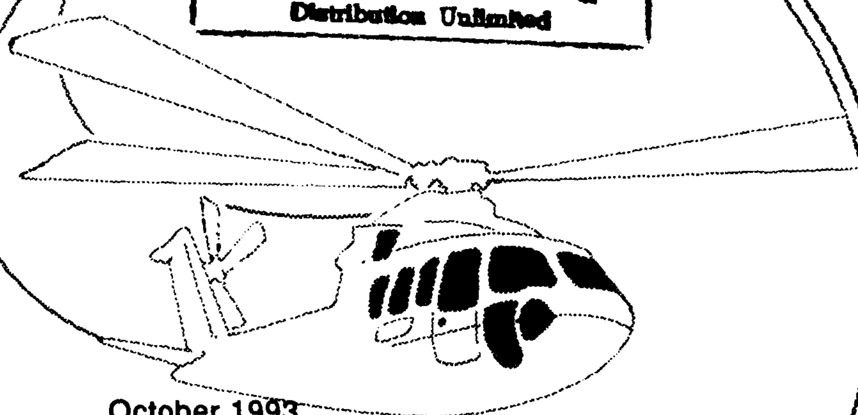
Rotorcraft Ditchings and Water-Related Impacts that Occurred from 1982 to 1989 - Phase I



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Final Report

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16. Abstract

This report documents Phase I of a two-phase program that investigates ditchings and water-related impacts for rotorcraft that occurred during the years 1982-1989. The main sources of accident data were the National Transportation Safety Board and the U.S. Army Safety Center. Data from a total of 89 accidents were obtained and examined for this study. Of these, 77 cases satisfied the criteria for inclusion into the database, 67 from the NTSB and 10 from the U.S. Army. In this report the impact and post-impact conditions were categorized to assess rotorcraft behavior and occupant survivability. Three impact scenarios and two post-impact scenarios were established. Special emphasis was placed on examining rotorcraft flotation equipment performance and post-impact survivability. Six representative case studies are presented to demonstrate aspects peculiar to the rotorcraft water impact and post-impact sequence that could not be adequately covered by the statistical categorizations alone. Recommended areas requiring enhancement of occupant survivability are presented.

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PREFACE

This report was prepared by Galaxy Scientific Corporation and Simula, Inc. under Contract No. DTFA03-89-C-00043 with the Federal Aviation Administration (FAA) Technical Center. The Project Manager at Galaxy Scientific Corporation was Dr. Charles C. T. Chen. Joseph W. Coltman, Gershon Yaniv, and Lindley W. Bark of Simula Inc. provided their expertise. Mr. Anthony Wilson of the FAA Technical Center acted as FAA Project Manager and Technical Monitor. The authors would like to thank Mr. William Adams of the Army Safety Center and Mr. Bill Broyles of the Navy Safety Center for their valuable assistance in acquiring data for this study.

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EXECUTIVE SUMMARY

This report documents Phase I of a two phase program that investigates ditchings and water-related impacts of rotorcraft that occurred during the years 1982-1989. The main goal of Phase I was to provide an assessment of current rotorcraft behavior in both ditchings and water-related impacts, aircraft and personal flotation equipment behavior, and occupant survivability in the water impact and post-impact environments. The main approach used in achieving this goal was to collect and examine data on water impacts that occurred during the target time period. From this body of data behavioral trends on the above-mentioned topics were determined and scenarios for impact and post-impact conditions were established.

Phase II of this project will focus on more specific airframe structural related factors, specifically, how the occupants interacted with the rotorcraft structure during the impact sequence and how this interaction caused injury. Specific ways of alleviating occupant injuries in water impacts will be identified and discussed. Finally, available analytical methods will be reviewed for their applicability to modeling rotorcraft water impacts.

The main sources of accident data were the National Transportation Safety Board in Washington, D.C., and the U.S. Army Safety Center in Fort Rucker, Alabama. Documentation for a total of 89 accidents was obtained and examined for this study. Of those accidents obtained, 77 cases met the criteria necessary for inclusion in this study, 67 from the NTSB and 10 from the U.S. Army. The nature of the information available for these water impacts included factual reports generated by the investigator, witness statements, and photographic documentation of aircraft damage.

The impact parameters, injury types, and injury causes were assessed based on the information drawn from reconstructions of the accident cases. This information was placed into a computerized data base which facilitated categorization and analysis. Special emphasis was placed on examining rotorcraft flotation equipment behavior and post-impact survivability. The results of these categorizations are presented and discussed. Three impact scenarios and two post-impact scenarios were established for rotorcraft ditching and water-related impacts and these are presented and discussed. Six representative case studies are presented to demonstrate aspects peculiar to the rotorcraft water impact and post-impact sequence that could not be adequately covered by the statistical categorizations alone. Areas requiring enhancement of occupant survivability are presented.

1. INTRODUCTION

Past examinations of rotorcraft crashworthiness were performed by the United States Army (*references 1 - 5*), and by the Federal Aviation Administration (reference 6). The focus of these investigations included all impact terrains. These investigations identified water as a crash environment very different than other terrains, because in addition to distinctive impact conditions, it imposes a variety of post-crash survivability problems. This effort specifically examines both the water impact and post-impact environments for rotorcraft to determine what factors affect occupant survivability and the current technology available to enhance occupant survivability.

The main goal of this investigation was to assess three areas related to occupant survivability for rotorcraft certified under Code of Federal Regulations, Title 14, Parts 27 and 29 (reference 7 and 8): impact conditions, occupant survivability hazards, and rotorcraft and occupant flotation equipment performance. These survivability areas were examined in rotorcraft ditchings and water impacts that occurred during the time period of 1982 to 1989. This report presents the results and conclusions from Phase I of this two-phase project. The Phase I effort consisted of three main tasks:

- Task I - Accident Reconstruction. Identify sources of rotorcraft water impact data for accidents that occurred between 1982 and 1989, obtain the data, and assess its suitability for the study. Use accident reconstruction techniques to determine the sequence of events, impact velocities and attitudes, occupant injuries and causes, impact structural damage, flotation performance, and post-impact survival aspects.

- Task II - Data Categorization. Using the data obtained and developed in Task I, generate statistics characterizing parameters such as impact velocities and attitudes, injury frequency and severity, and flotation availability and performance.

- Task III - Scenario Establishment. Through use of the accident data and trends identified in the categorization task, establish water impact scenarios that are representative of survivable impacts encountered in the data sample.

Phase II of this project will focus on more specific airframe structural related factors. Specify how the occupants interacted with the rotorcraft structure during the impact sequence and how this interaction caused injury. Specific ways of alleviating occupant injuries in water impacts will be identified and discussed. Finally, available analytical methods will be reviewed for their applicability to modeling rotorcraft water impacts.

This report is organized in a manner that reflects the first phase's progression. It describes the data acquisition and selection method, the accident reconstruction methodology, and the approach to categorization. Trends that can be ascribed to the

water impact and post-impact environments, including flotation equipment behavior, are developed. Scenarios for water impacts are also established, defined, and presented. This report analyzes the significance and interrelationships of the trends demonstrated by the data. Finally, improvements to the aircraft and survival equipment to enhance occupant water impact survivability, as supported by the findings in this investigation, are discussed. The appendices provide supplementary presentations of the accident data collected in this study, as well as documentation of the methods used in collection and reconstruction of the accidents.

2. BACKGROUND

Past improvements in occupant survivability have been supported by investigations that characterize the accident environment. Such definition of the accident conditions that an occupant is subjected to makes it possible to identify hazards and devise ways to reduce or eliminate those hazards. Typical impact scenarios are developed so that assessments of the aircraft structure under likely impact conditions may be made. In addition, how the occupant interacted with the aircraft structure and how this interaction caused injury is also examined.

2.1 PREVIOUS WORK

A general impact characterization study was performed for all rotorcraft and is documented in a 1985 DOT/FAA report titled Analysis of Rotorcraft Crash Dynamics for Development of Improved Crashworthiness Design Criteria (reference 6). This effort which evaluated survivable accidents occurring during 1974-1978 established a 95th percentile survivable velocity envelope; identified typical impact scenarios and hazards to occupants, and reviewed analytical techniques available for modeling rotorcraft and their occupants during impact events.

One of the scenarios identified by the aforementioned investigation was water impact which was recognized as hazardous. Of the 90 rotorcraft occupants in water impacts for the 1974-78 sample, 37 received serious or fatal injuries. That report recognized that the high percentage of fatalities found, 46.7 percent, was not solely caused by impact forces but also by the post-crash water environment. A high percentage of fatalities were ascribed to drowning and/or difficulty in exiting the aircraft (reference 6). This reduction in survivability in the post-crash environment helps to set water-related impacts apart from ground impacts. As a result of this difference, two of the areas recommended for development were post-crash egress and ditching/flotation characteristics (reference 6).

In addition to the post-crash survivability hazards discussed above, the impact conditions in water have also been identified as different than those experienced in a ground impact. In a water impact the landing gear of the rotorcraft does not absorb significant impact energy and the impact load is distributed over a wider contact area

(reference 6). Therefore there is a need to specifically examine the effects of a water impact on the structure of a rotorcraft and how the resulting damage affects occupant injury and survivability.

2.2 ROTORCRAFT AND THE WATER IMPACT ENVIRONMENT

Rotorcraft are used in many over water applications such as sightseeing and oil platform operations. In instances of in-flight emergencies, such as engine failure, the pilot often must perform a controlled landing on the water. A ditching is defined by the FAA (reference 9) as "an emergency landing on the water, deliberately executed, with the intent of abandoning the rotorcraft as soon as practical. The rotorcraft is assumed to be intact prior to water entry with all controls and essential systems, except engines, functioning properly."

Helicopters may be equipped with emergency flotation devices which can improve their performance after ditchings. These are inflatable bladders which are mounted either on the skids or on the sides of the lower fuselage. In an anticipated ditching situation, the pilot first arms and then inflates the floats. Some floats, however, deploy automatically upon water immersion. The primary purpose of these flotation devices is to keep the rotorcraft afloat and upright in a ditching situation to allow time for the occupants to safely egress.

In addition to the controlled rotorcraft ditchings as defined above, rotorcraft often impact water when the pilot has varying degrees of mechanical control of the aircraft. These situations are called water impacts in this report to differentiate them from controlled ditchings. For example, loss of a tail rotor followed by a pilot-guided descent to the water is not a ditching by definition, but rather a water impact. Another relatively common example of an impact during over-water operations is a sudden, unexpected in-flight collision with the water. This often occurs in poor visibility conditions such as in bad weather or darkness and is a result of the pilot losing altitude reference and flying the aircraft into the water.

Regardless of whether the touchdown was a ditching or a water impact, rotorcraft have a natural tendency to invert because of their inherent high center of gravity. Exiting from an inverted cabin underwater after an impact can be difficult. The psychological shock of suddenly being in an inverted, flooded cabin can add to the confusion caused by a hard or unexpected touchdown. This compounded psychological shock can add to the difficulty of successful occupant egress. This study examined the events at impact and after impact, for both ditchings and water impacts, to analyze the behavior of the aircraft and occupant survivability in this environment.

3. TECHNICAL APPROACH

The main goal of this investigation was to assess three areas relating to occupant survivability for FAR 27 and FAR 29 rotorcraft for the years 1982 to 1989:

- impact conditions
- occupant survivability hazards
- rotorcraft and occupant flotation equipment performance

The main approach used in achieving this goal was to collect and examine data documenting specific incidents of water impacts that occurred during the prescribed time period. From this body of data, specific trends related to the aforementioned areas were then determined.

3.1 DATA ACQUISITION AND SELECTION

To properly assess the areas presented above in this section, the data sample was required to contain a significant representation of water impact survivability experienced by the civilian rotorcraft fleet during the years 1982 to 1989. The sample had to be of a size that contained a significant number of severe but survivable accidents. Based on previous trend investigations a target number of 80 to 100 accidents was established.

Next, sources of accident data had to be identified. The National Transportation Safety Board (NTSB), U.S. Army, U.S. Navy, and International Civil Aviation Organization (ICAO), were considered potential sources of data. The main source of accident data was the National Transportation Safety Board (NTSB) in Washington, D.C. The Accident/Incident Data System (AIDS), maintained by the Federal Aviation Administration, was used as a search cross-reference and proved valuable in identifying accidents in the NTSB database that were not located by the initial NTSB searches. Additional accident data was obtained from the U.S. Army Safety Center located at Fort Rucker, Alabama. Accident data was also identified by the International Civil Aviation Organization (ICAO); however, the U.S. accidents which were of interest were obtained from the NTSB. Appendix A contains a listing of the sources for accident data and the number of accidents obtained from each. It also illustrates the variable results encountered for different inquiries to the same body of data. Table 3.1 summarizes the data sources that were identified and the number of reports from each source that were determined to be suitable for this investigation. A total of 89 accident cases with supporting documentation were obtained.

The reports located were judged on the quality and depth of their documentation to assess their usefulness in supporting accident reconstruction. Therefore, not all

Table 3.1 Summary of Data Search, Acquisition, and Selection

Accident Data Source	Number Identified	Number Obtained	Number Obtained but Excluded **	Number Used in Study
NTSB	72	72	5	67
U.S. Army	17	17	7	10
U.S. Navy	21	0	0	0
ICAO *	39	0	0	0
TOTALS	**149**	**89**	**12**	**77**

* Note: U.S. accident reports identified through ICAO were obtained through the NTSB and are counted in the NTSB numbers.

** Note: These accidents were excluded because either they were ground impacts or the aircraft were not representative of the civilian rotorcraft fleet.

accidents found in the data search were obtained for further examination (see table 3.1). The method used to collect the data for this investigation creates an inherent bias towards higher severity accidents and the trends presented in this report should be reviewed with this point in mind. Unfortunately, less severe accidents are often not well documented in terms of detailed aircraft damage or occupant injuries. Section 4.0, Accident Sample Summary, presents summary accident statistics for the years studied to give an indication of this bias.

The criteria used to determine inclusion of an accident report into this study were:

- the impact was with water
- the impact occurred between the years 1982-1989
- the aircraft involved had to be representative of the civilian rotorcraft fleet

Several accident reports obtained from the NTSB and the U.S. Army, despite use of water impact as an initial search criterion, were actually ground impacts and therefore were not reconstructed or entered into the database. Two accidents involving Bensen Gyrocopters were not considered relevant to the database because they were not felt to be representative of the civilian rotorcraft fleet. U.S. Army data was considered relevant because of the similarities between U.S. Army helicopters and equivalent civilian models. The pursuit of detailed accident data from the U.S. Navy, identified as a potential source, was restricted by the project schedule. In all, 77 of 89 accident reports obtained met the selection criteria and were included in this study.

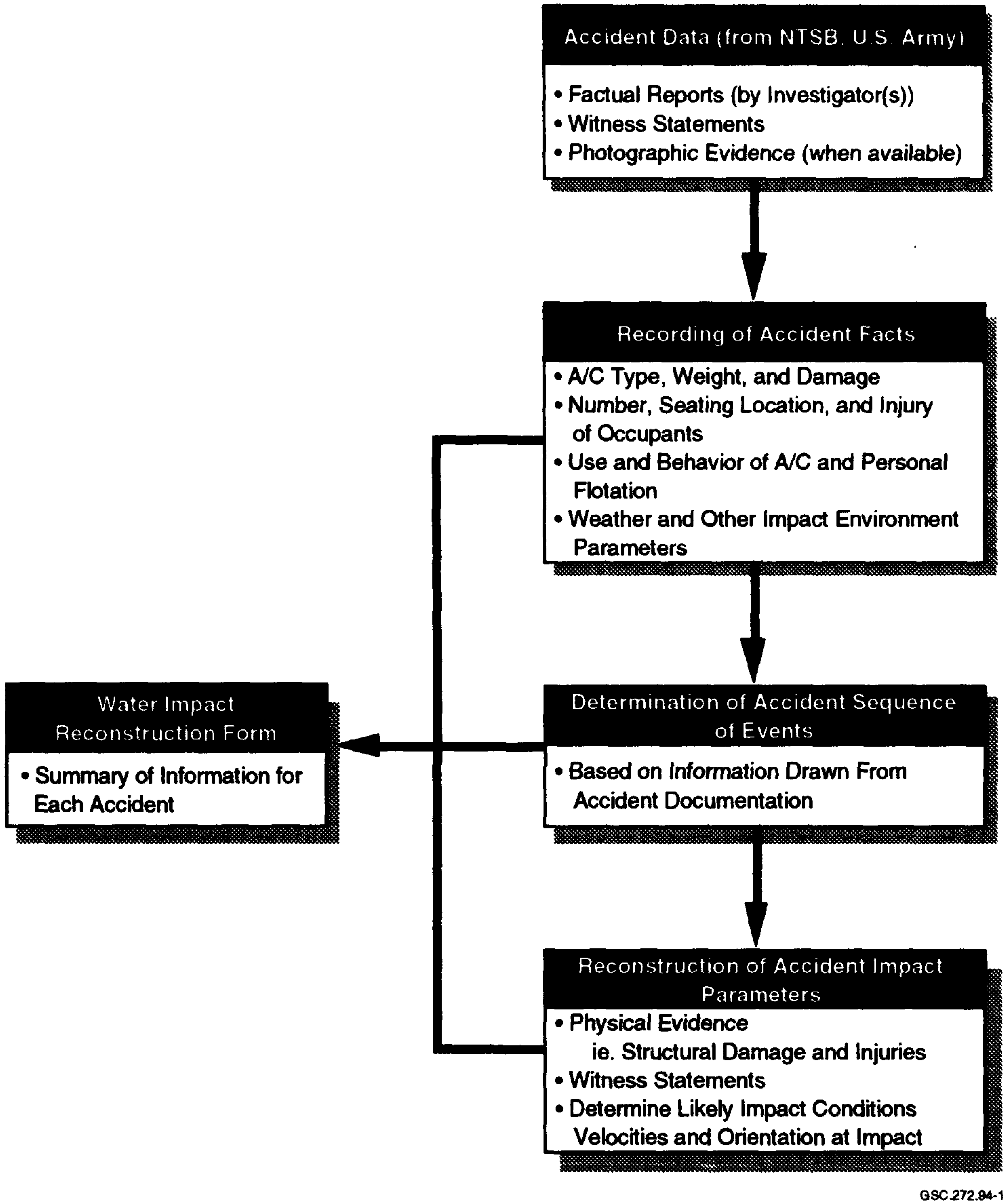

Figure 3.1 Water Impact Accident Reconstruction Process

3.2 ACCIDENT RECONSTRUCTION

Figure 3.1 outlines the accident reconstruction process used in this investigation. Documentation for the 89 accidents was examined and/or obtained for this study from the NTSB and the U.S. Army Safety Center. The available information relating to these accidents included factual reports generated by the investigator(s), witness statements,

and photographic documentation of aircraft damage. The impact velocities and attitudes, aircraft impact damage, and personal injury data, were drawn from each accident report and summarized in a water impact reconstruction form developed for this study. These water impact reconstruction forms facilitated collection, categorization, and analysis of the necessary information. Appendix B contains a sample water impact reconstruction form and complete documentation of the formats used to summarize the data taken from the accident reports. Special emphasis was placed on examining rotorcraft flotation equipment performance and post-impact occupant survivability. Environmental conditions, such as wave height and water temperature, and their effects on occupant survivability were recorded.

It should be noted that the accident reconstruction of water impacts entails unique challenges. In ground impacts, the impacted surface may provide evidence in the form of gouges, broken tree limbs, and similar physical traces. This information is not as available in water impacts. Also, in a ground impact the aircraft is generally available for more detailed examination to determine impact attitude, accelerations, and structural damage. An aircraft involved in a water impact may not be recovered or may be further damaged by post-impact wave action or recovery, thereby masking damage caused by the impact. Witness statements describing the impact were used in conjunction with documentation of the structural damage to assess which damage was caused by the impact. Photographic evidence of recovered aircraft structural damage facilitated this process by providing a visual reference. The nature of the evidence available for this study was not comprehensive enough to establish the crash pulses with a reasonable degree of certainty in all cases and therefore, they are not presented. A sample of the accident reconstruction methodology can be found in Appendix C.

3.3 DATA CATEGORIZATION

The impact parameters, injury data, and flotation data were categorized to define water impact conditions and support the establishment of typical survivable water impact and post-water impact scenarios. The categorization effort was organized into five main areas:

- Accident Sample Summary - This area examines the sample according to yearly number of occurrences, data source, aircraft weight class, level of accident survivability, aircraft configuration, and first accident event.

- Impact Parameters - This area examines the distribution of impact attitudes for survivable and partially survivable accidents and the 95th percentile velocities for survivable/partially survivable and significant survivable groups. Impact scenarios are defined. The 95th percentile significant survivable impact velocities in the current sample are compared with other available data, U.S. Navy water impacts, and all helicopter impact terrain results.

- Injury Causes and Severity - This area examines the impact injury types and causes, impact injury occurrence relative to occupant restraint, the frequency of occurrence and severity of impact injuries relative to aircraft weight class, the frequency of occurrence of post-impact injuries and causes.

- Aircraft Flotation - This area examines the wave heights encountered, the number of aircraft equipped with flotation, the number of aircraft with deployed flotation, and the effect of flotation on aircraft water stability and occupant injury.

- Personal Flotation - This area examines occupant egress, personal flotation availability, use and performance, and occupant exposure to the post-impact environment. It also examines personal flotation availability and performance relative to drowning occurrences.

The data for these categorizations were drawn from reconstructions of the available accident cases. A computerized database was created to facilitate manipulation and analysis of the accident data. The database definitions were based on the data collection definitions used in the water impact reconstruction forms for simplified input. For documentation of this database, including a flow chart and data definitions, refer to Appendix D. Sections 4 through 7 of this report contain the results and a discussion of these categorizations summarized in graphical form.

4. DATA SAMPLE SUMMARY

It is important to consider the overall composition of the data sample before examining it in detail about specific survivability aspects. Therefore, before discussing the impact conditions, survivability hazards, and flotation equipment performance several basic data categorizations will be presented in this section to introduce the data sample. These categorizations are:

- yearly distribution of accidents by data source

- distribution by aircraft weight class and data source

- distribution by level of survivability and data source

- distribution by first accident event

The influence of some of these basic distributions, especially by data source (NTSB, U.S. Army) and by aircraft weight class are reflected throughout the other sections of this report.

4.1 YEARLY DISTRIBUTION OF ACCIDENTS BY DATA SOURCE

Determining the distribution of accidents in the data sample by year is one means of determining how representative the sample is of the accident history of the years being studied. A previous effort examining all helicopter impacts for the years 1974 through 1978 found that water was the impact terrain for 11 percent of the sample (reference 6). For that investigation, which examined occurrences covering a five year span, a total sample of 311 accident cases were obtained for study. Using the 11 percent water terrain statistic, that sample contained an average of 6.8 water impact accidents per year during the 1974-1978 time period. This present investigation, which focuses on an eight year period, has an average of 9.6 water impact accident cases per year. A major factor in the rise in water impacts in this current sample is the increased use of helicopters in support of ocean oil drilling operations in the mid-1980's. Figure 4.1

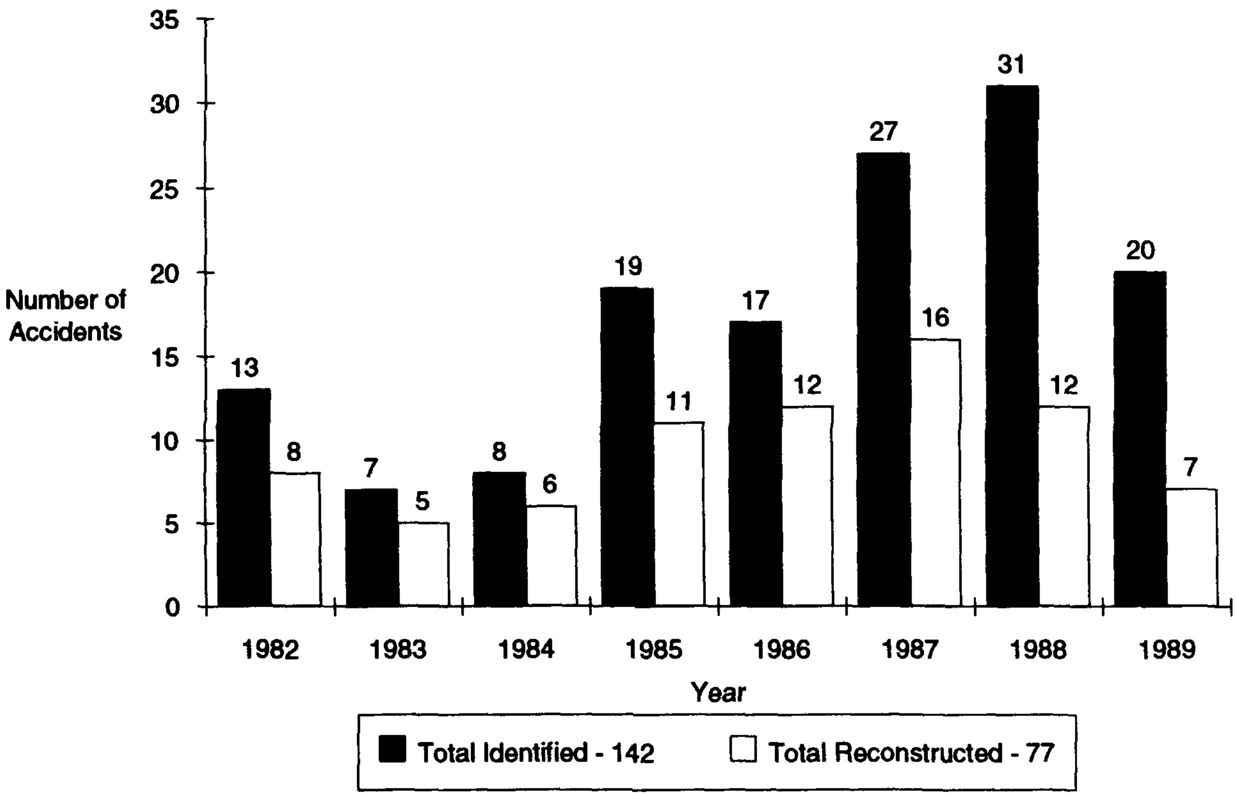

Figure 4.1 Yearly Distribution of Civilian (NTSB and AIDS) and U.S. Army Accidents Identified and Reconstructed

shows the yearly distribution of accidents reconstructed relative to the yearly distribution of those accidents identified as potential data for this study from civilian (NTSB and AIDS) and U.S. Army sources.

4.2 DISTRIBUTION OF AIRCRAFT BY WEIGHT CLASS AND DATA SOURCE

Examining the composition of the data sample by aircraft weight class is useful because it is another means of determining that the sample is representative of the overall aircraft fleet, by aircraft weight and size, that it attempts to depict. The aircraft in this sample were categorized into four weight classes (based on design gross weight) for analysis:

- weight class A - less than 2500 pounds
- weight class B - 2501 to 6000 pounds
- weight class C - 6001 to 12500 pounds
- weight class D - above 12500 pounds

Aircraft that fell within weight classes A and B correspond to Code of Federal Regulations, Title 14, Part 27 rotorcraft and those that fell within weight classes C and D correspond to Code of Federal Regulations, Title 14, Part 29 rotorcraft. As can be seen in table 4.1, weight class B was the most predominant rotorcraft weight class found in this study. Table 4.2 presents the distribution of civil rotorcraft by weight class as of October 1988. By comparing the numbers in table 4.1 with table 4.2, it is apparent that the weight class distribution in the water impact sample does reflect the weight distribution of the U.S. civil fleet as of October 1988.

Table 4.1 Water Impact Accident Distribution by Data Source and Aircraft Weight Class

Aircraft Weight Class	Number of Aircraft by Data Source		Total Aircraft
	NTSB	U.S. Army	
A	14	0	14
B	41	4	45
C	10	3	13
D	2	3	5
TOTALS	**67**	**10**	**77**

Table 4.2 Distribution of U.S. Civil Helicopters by Weight Class as of October 1988 *

WEIGHT CLASS	A	B	C	D
MAXIMUM GROSS TAKE-OFF WEIGHT (LB)	<2,500	2,501-6,000	6,001-12,500	>12,500
MANUFACTURER AND MODEL (quantity registered is shown in parentheses)	Bell 47 (1,496) Hynes Hz (155) Robinson R-22 (365) Schweizer 269 (779)	Aerospatiale 315,316,318, 319,341,350, 355 (642) Augusta 109 (86) Bell 206 (2302) Enstrom F-28, 280 (518) Hynes H5 (15) MBB 105 (143) MDHC 500 (746) Rogerson/Hiller UH-12 (767)	Aerospatiale 360,365 (26) Bell 204,205, 222,412 (583) Boeing HUP, H21, 42A (17) MBB BK117 (63) Sikorsky S-56, S-51, S-52, S-55, S-62, S-76 (392)	Aerospatiale 330,332 (18) Bell 214,301 (36) Boeing 107, 234,360 (27) Sikorsky S-58, S-61,S-64, S-70 S-72 (241) Westland 30 (9)
TOTAL IN WEIGHT CLASS	2,795	5,219	1,081	331

* Table taken from reference 11

4.3 DISTRIBUTION OF ACCIDENTS BY SURVIVABILITY, WEIGHT CLASS, AND DATA SOURCE

The distribution of accidents according to the level of survivability provides an important overall look at the levels of accident severity being examined in this program. Also, by examining accident survivability relative to aircraft weight class, impact survivability trends that might be ascribed to aircraft weight class can be identified. The data is categorized by data source to better support the analysis performed in Phase I presented later in this report, which examines civilian data only. Table 4.3 presents the results of this categorization. There were a total of 60 survivable and partially survivable civilian accidents in the data sample, with a further seven civilian accidents being nonsurvivable. There were a total of nine survivable and partially survivable U.S. Army accidents in the data sample, with one additional accident being nonsurvivable. For the civilian accidents the partially survivable and nonsurvivable accidents are concentrated in the lighter weight classes of A and B.

Table 4.3 Distribution of Accident Survivability by Data Source and Aircraft Weight Class

Aircraft Weight Class	Number of Accidents by Data Source and by Level of Accident Survivability *						Total Accidents
	NTSB			U.S. Army			
	S	PS	N	S	PS	N	
A	13	0	1	0	0	0	14
B	32	3	6	3	0	1	45
C	10	0	0	3	0	0	13
D	2	0	0	1	2	0	5
TOTALS	**57**	**3**	**7**	**7**	**2**	**1**	**77**

* S = Survivable, PS = Partially Survivable, N = Nonsurvivable

The nonsurvivable U.S. Army accident was a weight class B aircraft, while the two partially survivable U.S. Army accidents were both weight class D aircraft. In general lighter aircraft would be more expected to expose occupants to impact hazards than heavier aircraft, and the civilian data appears to support this expectation. An examination of impact injuries relative to aircraft weight class would be more illustrative in determining this trend. Such an examination is presented later in section 6.

The distribution of the number of occupants relative to overall injury severity level, data source, and accident survivability, provides useful reference information. These categorizations are summarized in table 4.4. There are several important totals that can be drawn from this table. The first is there were 204 total occupants in civilian survivable and partially survivable accidents. Of these 204, a total of 26 (13 percent) were fatally injured, a further 29 (14 percent) were seriously injured, and 37 (18 percent) sustained minor injuries. The causes and exact nature of these injuries will be more closely examined in section 6.

Table 4.4 Distribution of Overall Occupant Injury Severity Level by Data Source and Accident Survivability

Overall Occupant Injury Severity Level	Number of Occupants by Data Source and by Level of Accident Survivability *						Total Occupants
	NTSB			U.S. Army			
	S	PS	N	S	PS	N	
Fatal	20	6	15	0	3	1	46
Serious	24	5	0	5	4	1	37
Minor	35	2	0	3	0	0	42
None	112	0	0	17	0	0	128
TOTALS	**191**	**13**	**15**	**25**	**7**	**2**	**253**

* S = Survivable, PS = Partially Survivable, N = Nonsurvivable

The percentage of occupants that were seriously or fatally injured in the current sample, 27 percent, is considerably lower than the 47 percent found for water impacts in a previous program (reference 6). Factors that could account for this discrepancy may include improved flotation equipment and shorter rescue response time in the current sample. Also, the distribution of accident severity may have differed in the water impacts examined in the earlier sample.

4.4 DISTRIBUTION OF ACCIDENTS BY FIRST ACCIDENT EVENT

The first accident event is the first occurrence in the chain of events leading to the mishap. This event can be used to get an overall perspective on the initiating causes of the accidents in the data sample. A distribution of the first event for the entire sample was compiled and is shown in table 4.5. The definitions for these first events follow those used by the NTSB and for those accidents reconstructed from NTSB reports the finding of the investigator(s) was used. As can be seen in table 4.5, a failure or malfunction of the airframe or some component or system was the single leading first event occurrence. However, if the loss of power categories are grouped together, then loss of power becomes the single leading first event occurrence (40 percent). Loss of power would be expected to be the most numerous first event in this data sample because engine malfunction is considered in the FAA definition of a ditching. In-flight collision with terrain is the last major group of data points, and this event as a first occurrence suggests little or no advance warning of impact for the pilot. In fact, an accident of this type, an impact that occurred at night, is presented in section 8.3 of this report as a case study.

Table 4.5 Distribution of First Event Occurrence, Total Sample

Type of First Event	Number of Occurrences
Airframe/Component/System Failure or Malfunction	18
Forced Landing	2
In Flight Collision With Object	4
In Flight Collision With Terrain	11
In Flight Encounter with Weather	2
Loss of Control - In Flight	4
Loss of Power (Unspecified Cause)	10
Loss of Power (Total) Mech. Failure/Malfunction	9
Loss of Power (Partial) Mech. Failure/Malfunction	2
Loss of Power (Total) Non-mechanical	9
Loss of Power (Partial) Non-mechanical	1
Other	5
TOTAL	**77**

4.5 INCLUSION OF U.S. ARMY DATA

U.S. Army accidents were included in the sample for this program because of the similarities between U.S. Army helicopters and equivalent civilian models. These 10 U.S. Army accident cases contained well-documented descriptions of the aircraft impact parameters, occupant injuries, and aircraft structural damage. As a representation of severe yet survivable accidents they provide valuable survivability information. However, the more rigorous flight missions and more extensive use of protective flight equipment in the U.S. Army accidents made correlation within a civilian study difficult. The greater level of accident severity in the U.S. Army cases was reflected in higher numbers of seriously and fatally injured occupants. From table 4.4 it can be shown that, in survivable and partially survivable accidents, 38 percent of U.S. Army occupants sustained fatal or serious injury levels, compared with 27 percent of civilian occupants involved in similar severity accidents. Additionally, it was found that velocity percentiles were skewed upwards by including U.S. Army data.

Therefore, the 10 U.S. Army accidents are not considered in the Phase I analysis examining impact conditions, survivability hazards, and flotation equipment. The U.S. Army accidents are considered in the Phase II analysis which focuses more on occupant interaction with structure during the impact sequence, as well as aircraft impact damage. It is felt that the survivability information that these accidents contain can be better applied for civilian purposes if examined in these areas.

5. CHARACTERIZATION OF IMPACT CONDITIONS

One of the primary goals of this program was to characterize the impact conditions found in rotorcraft ditchings and water impacts. The impact velocities and impact attitudes of the rotorcraft are critical parameters that describe the conditions that the rotorcraft and its occupants are being subjected to in an impact. The factors that can affect the impact parameters include the mission of the aircraft, the altitude of flight, the occurrence that causes the aircraft's descent, and the impact surface, among others. The magnitudes of these parameters at impact are of interest because they are factors that can affect impact survivability for the occupants as well as the post-impact flotation and trim of the rotorcraft. Therefore this section attempts to determine percentiles for the impact parameter magnitudes found to be survivable. Water entry of the rotorcraft as it affected post-impact flotation performance is discussed in the section on aircraft and occupant flotation later in section 7 of this report.

It should be emphasized that in this section only civilian survivable and partially survivable accidents are considered. The U.S. Army accidents were found to skew the survivable velocity percentiles upwards, especially in the longitudinal direction, because of different flight missions for these aircraft and more extensive use of crash protection for the occupants. Therefore the impact parameters for the U.S. Army accidents are not included in this section. The impact parameters for nonsurvivable accidents are not

considered because these accidents represent situations where crashworthiness improvements would be impractical.

The aircraft attitude (pitch, roll, and yaw) and impact velocities (longitudinal, vertical, and lateral in aircraft coordinates) are presented in this section. Examination of these parameters enables the impacts to be grouped into categories which facilitates the definition of impact scenarios. These impact scenario definitions are presented later in this section. Post-impact scenarios, based on the time that the aircraft remained upright after touchdown, are also presented. The results throughout this section are compared with the kinematics results of the 1974-78 sample involving rotorcraft impacts of all terrain types (reference 6). The significant survivable velocities for this current effort are also presented in this section, including comparison with both the 1974-78 data sample and a 1972-81 U.S Navy water impact study (reference 10). The definition of velocity envelopes for increasing injury severity were attempted but could not be established with certainty because of an insufficient number of data points combined with wide scatter.

5.1 AIRCRAFT IMPACT ATTITUDE

The first impact parameters that will be discussed are the impact attitude angles. This data is a result of the accident reconstruction task described in the Technical Approach, Section 3.0, and was developed from the aircraft attitude at impact based on factual reports, witness statements, structural damage descriptions, and photographic evidence where available. Reconstruction of the impact angles was not possible in some of the cases due to insufficient evidence, the number of unknown values is noted for each parameter.

Table 5.1 presents the distribution of the impact pitch angles. A pitch angle magnitude could be determined in 53 of the 60 survivable and partially survivable civilian accidents. Of the known pitch angles, 96 percent fell between $\pm$ 20 degrees. A total of 32 of the 53 known pitch angles (60 percent) indicate either a level or nose up attitude for the aircraft at impact. Two accidents had severe nose down pitch angles at impact, one in the 51 to 60 degree range and the other in the 81 to 80 degree range. These two accidents were both partially survivable and will be shown later in this section to satisfy the definition of impact scenario three defined for this program.

The impact roll angle distribution is presented in table 5.2. The roll angle could be determined in a total of 50 of the 60 civilian survivable and partially survivable accidents. The roll angle was between $\pm$ 20 degrees for 92 percent of the known values. The distribution is slightly biased towards the right side down values, with 14 of the 24 non-level roll angles (58 percent) being right side down. A similar trend was also noted in the all impact terrain study but with inconclusive results (reference 6). It was stated in several cases that the pilot rolled the aircraft deliberately to the right at impact to stop

Table 5.1 Distribution of Impact Pitch Angle for Survivable and Partially Survivable ^ccidents

Angle (deg)	Number of Accidents: Per Direction: Up	Level	Down	Total Accidents	Percent of Accidents	Cumulative Percent
0		7		7	13.21%	13.21%
1 - 10	22		10	32	60.38%	73.58%
11 - 20	3		9	12	22.64%	96.23%
21 - 30	0		0	0	0.00%	96.23%
31 - 40	0		0	0	0.00%	96.23%
41 - 50	0		0	0	0.00%	96.23%
51 - 60	0		1	1	1.89%	98.11%
61 - 70	0		0	0	0.00%	98.11%
71 - 80	0		0	0	0.00%	98.11%
81 - 90	0		1	1	1.89%	100.00%
91 -120	0		0	0	0.00%	100.00%
121 - 150	0		0	0	0.00%	100.00%
151 - 180	0		0	0	0.00%	100.00%
TOTAL				**53**	**100.0%**	
Unknown				**7**		

Table 5.2 Distribution of Impact Roll Angle for Survivable and Partially Survivable Accidents

Angle (deg)	Number of Accidents: Per Direction: Left	Level	Right	Total Accidents	Percent of Accidents	Cumulative Percent
0		26		26	52.00%	52.00%
1 - 10	5		10	15	30.00%	82.00%
11 - 20	3		2	5	10.00%	92.00%
21 - 30	0		1	1	2.00%	94.00%
31 - 40	1		0	1	2.00%	96.00%
41 - 50	1		0	1	2.00%	98.00%
51 - 60	0		1	1	2.00%	100.00%
61 - 70	0		0	0	0.00%	100.00%
71 - 80	0		0	0	0.00%	100.00%
81 - 90	0		0	0	0.00%	100.00%
91 - 120	0		0	0	0.00%	100.00%
121 - 150	0		0	0	0.00%	100.00%
151 - 180	0		0	0	0.00%	100.00%
TOTAL				**50**	**100.00%**	
Unknown				**10**		

the rotor blades from rotating and thereby aid egress. This is a result of rotorcraft pilot training which specifies this right roll so that when the forward moving blades (rotating counter-clockwise for this example) hit resistance the reactive moment will tend to drive the transmission to the rear, away from the passenger compartment.

The yaw angle distribution for the total sample is given in table 5.3. The yaw angle was difficult to determine, especially in cases involving a yaw rate. Witness statements were often contradictory or unreliable. In those cases for which a value could be assigned, 74 percent of the values were approximately equal to 0 degrees.

Table 5.3 Distribution of Impact Yaw Angle for Survivable and Partially Survivable Accidents

Angle (deg)	Number of Accidents Per Direction				Percent of Accidents	Cumulative Percent
	Left	Level	Right	Total Accidents		
0		37		37	74.00%	74.00%
1 - 10	3		0	3	6.00%	80.00%
11 - 20	2		2	4	8.00%	88.00%
21 - 30	0		4	4	8.00%	96.00%
31 - 40	0		0	0	0.00%	96.00%
41 - 50	0		0	0	0.00%	96.00%
51 - 60	0		0	0	0.00%	96.00%
61 - 70	0		0	0	0.00%	96.00%
71 - 80	0		0	0	0.00%	96.00%
81 - 90	0		1	1	2.00%	98.00%
91 - 120	0		0	0	0.00%	98.00%
121 - 150	0		0	0	0.00%	98.00%
151 - 180	0		1	1	2.00%	100.00%
TOTAL				**50**	**100.00%**	
Unknown				**9**		

5.2 AIRCRAFT IMPACT VELOCITIES

The velocity magnitudes presented in this section represent the initial impact velocity components that could be estimated based on the evidence contained in the accident reports. It should be emphasized that the initial impact velocity is not the same as the velocity change, which is a function of the stopping distance. The magnitude and duration of the velocity change experienced by the occupants during the principal impact critically affect their ability to survive the impact. In instances where a longer stopping distance is available, as in a primarily longitudinal impact with a shallow flight path angle, a higher initial impact velocity may be survivable. The total stopping distance, especially in the longitudinal direction, was difficult to determine for some cases in this sample. This difficulty was caused by the lack of physical evidence, such as skid marks or gouges, in the water impact. As the findings for each velocity

component are presented, their significance with respect to velocity change and occupant survivability is discussed.

The magnitude of the vertical impact velocity could be determined in a total of 53 of the 60 (88 percent) civilian survivable and partially survivable accidents. This velocity component is approximately parallel to the orientation of the spine of a seated occupant and therefore the threshold that is found survivable is highly dependent on the tolerance of the human spine to acceleration in this direction. The cumulative frequency of the 53 known velocity magnitudes is shown in figure 5.1. It can be seen from figure 5.1 that

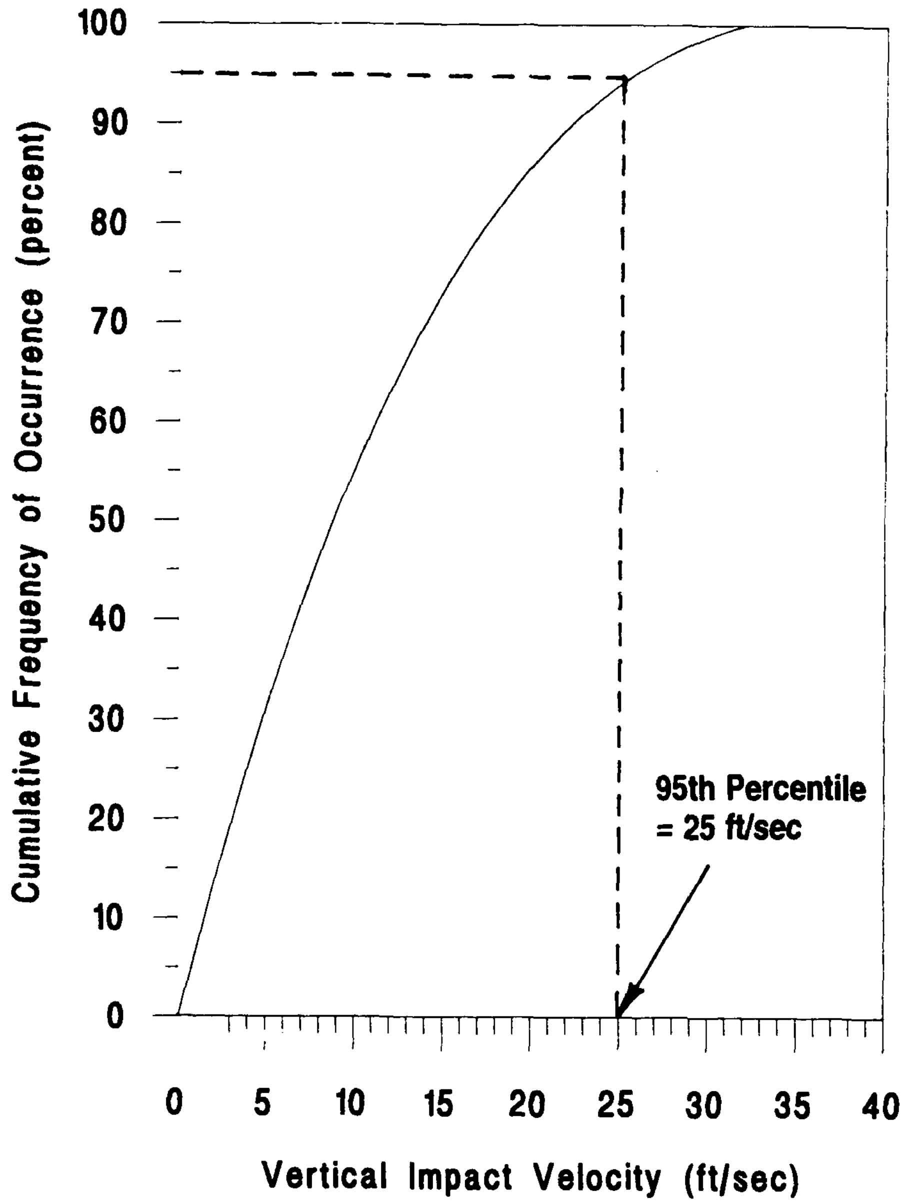

Figure 5.1 Cumulative Frequency of Occurrence of Vertical Impact Velocity for Survivable and Partially Survivable Accidents

the 95th percentile value for survivable and partially survivable impacts was 25 ft/s. This value is comparable to 24 ft/s found for survivable and partially survivable accidents in a study that examined all rotorcraft impact terrains (reference 6). In the vertical direction, the initial impact velocity could be considered to be approximately equal to the velocity change, assuming very little rebound occurred.

Longitudinal impact velocity magnitudes could be determined in a total of 51 out of 60 (85 percent) of the civilian survivable and partially survivable accidents. As previously discussed, these values represent initial impact velocities only and are not necessarily the velocity change experienced by the occupants during the principal impact. The cumulative frequency of the longitudinal velocities is presented in figure 5.2. In figure 5.2, the 95th percentile value for the longitudinal velocity is seen to be 56 ft/s. By comparison, the initial impact velocity value found for survivable and partially survivable accidents in the all impact terrain study was approximately 50 ft/s (reference 6).

The lateral impact velocity magnitude could be determined in a total of 51 out of 60 (85 percent) of the civilian survivable and partially survivable accidents. A plot of the cumulative frequency of occurrence of lateral impact velocity, shown in figure 5.3, demonstrates that the 95th percentile value was 15 ft/s. The value found for survivable and partially survivable accidents in the all impact terrain study was approximately 10 ft/s. There were two occurrences of lateral velocities above 20 ft/s in the current sample, however, one was a primarily vertical impact with a high yaw rate and the other was a primarily longitudinal impact with approximately 30 degrees of yaw. In neither of these cases, then, was the lateral velocity the primary velocity component that affected the occupants.

5.3 COMPARISON OF CURRENT WATER IMPACT VELOCITIES WITH PREVIOUS FINDINGS

A subset of the survivable and partially survivable accidents are those more severe accidents, defined as significant survivable, in which impact injuries are sustained by the occupants. When attempting to determine crashworthiness improvements that can lessen occupant impact injuries, examination of these severe accidents is more informative. This classification of accident data also proves useful when comparing data with other studies that used similar definitions. A discussion of the significant survivable impact conditions found in this current effort compared to those values available from other studies will provide perspective on the relative impact severity of the civil water impact environment.

The 95th percentile velocity magnitudes from two other characterization studies will be used for comparison purposes. The first study was performed for the U.S. Navy and it examined significant survivable impacts of both rotorcraft and fixed wing aircraft (reference 9). Comparison with this study is useful because it, like this current effort,

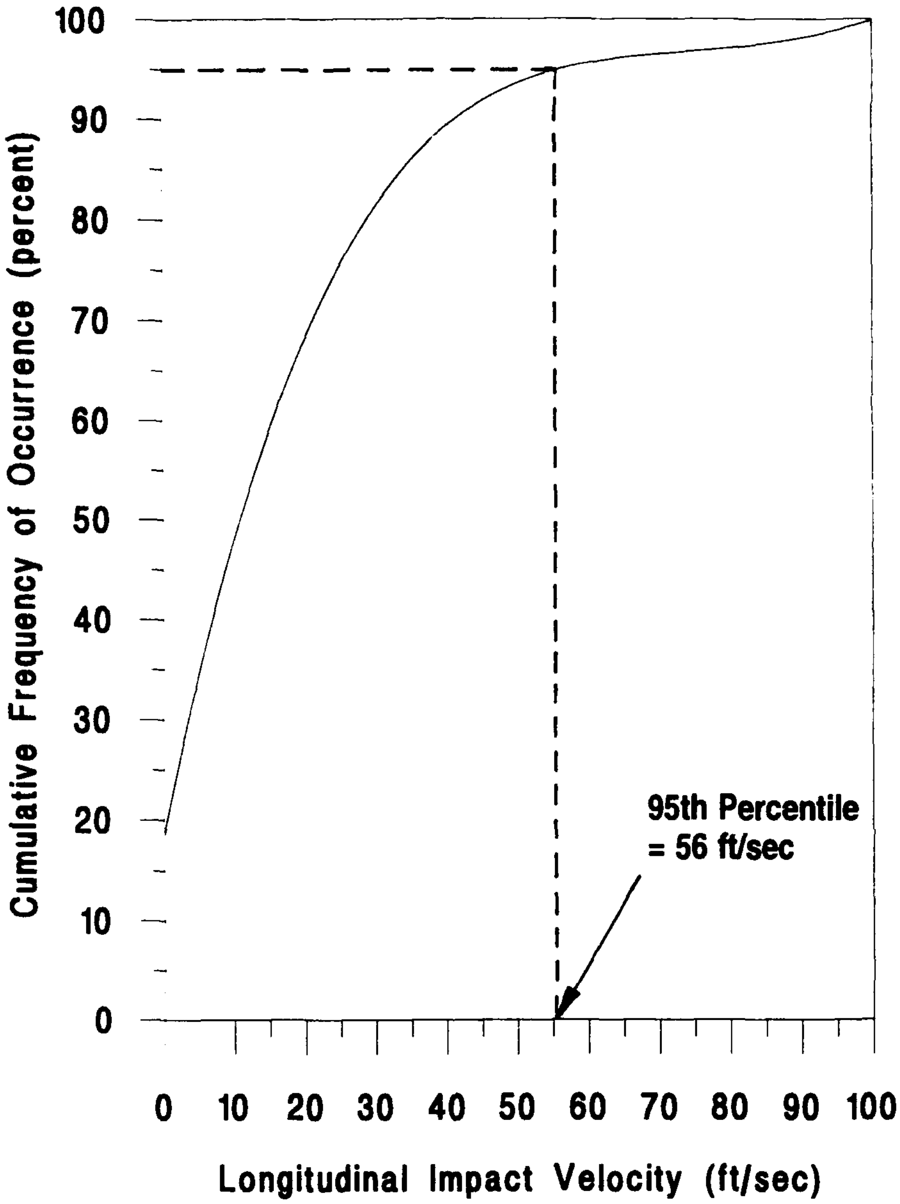

Figure 5.2 Cumulative Frequency of Occurrence of Longitudinal Impact Velocity for Survivable and Partially Survivable Accidents

specifically examined the water impact of rotorcraft. The second study was sponsored by the FAA and it examined civil rotorcraft impacts on all terrain types (reference 6). This second program, although it did not focus solely on water impacts, was a civil study and therefore the flight missions of the aircraft would be expected to correlate better with this current effort. To aid in comparing the three samples, the definitions used by each to define significant survivable are presented in table 5.4. The velocity magnitudes are presented in table 5.5 for comparison of all three samples. It should be noted that the values given in the U.S. Navy study were presented as velocity changes while those in the civil study were initial impact velocities, as are the velocities in this current effort.

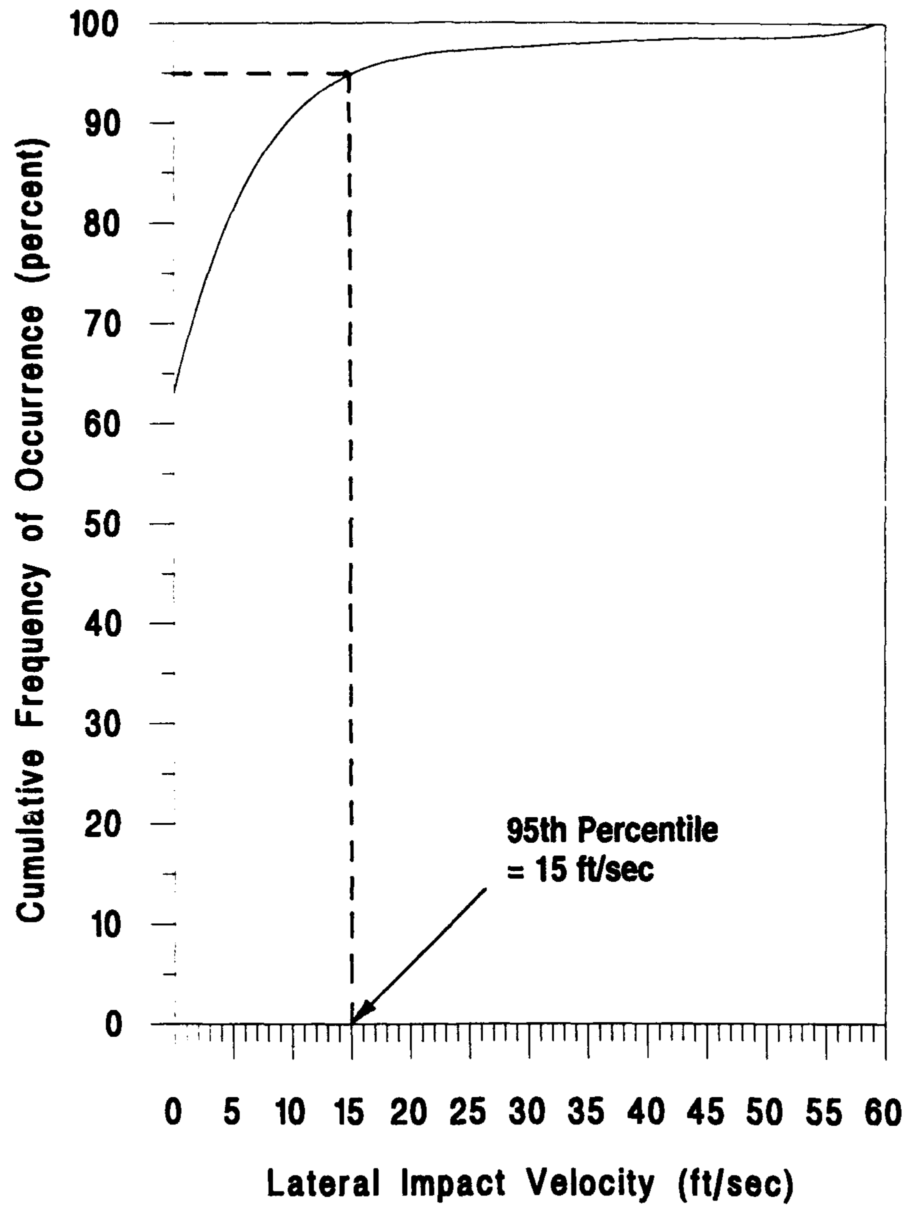

Figure 5.3 Cumulative Frequency of Occurrence of Lateral Impact Velocity for Survivable and Partially Survivable Accidents

A comparison of the 95th percentile longitudinal velocities for the three samples illustrates the significant difference between initial impact velocity and velocity change and suggests that U.S. Navy water impacts are survivable at higher velocities. In table 5.5 it can be seen that in the longitudinal direction, the current water impact sample nominally compares more favorably with the U.S. Navy sample. It must be remembered, however, that the U.S. Navy value probably represents a more severe level of survivability because it represents the velocity change and not just the initial impact velocity. Several factors can be identified that account for the disparity between

Table 5.4 Comparison of Survivability Definitions Used in Other Accident Samples

Sample	Definition
Water-Related Impact 1982-89	• deemed survivable or partially survivable • personnel injuries due to impact
U.S. Navy Water Impacts 1972-81	• one or more major injuries to occupants • substantial structural damage
All Helicopter Impacts 1974-78	• deemed survivable or partially survivable - post crash fire - personnel injuries - substantial structural damage

Table 5.5 Comparison of 95th Percentile Velocity Magnitudes for Significant Survivable Accidents with Other Impact Environments

Velocity Component	Water-Related Impact - Present Study	U.S. Navy Water Impacts (1)	All Helicopter Impacts
	95th Percentile Velocity Values (ft/s) for Significant Survivable Accidents		
longitudinal	77	72	50
vertical	28	39	26
lateral	24	42	10
	Notes: Period: 1982-1989 water impact	Notes: Period: 1972-1981 water impact portion only	Notes: Period: 1974-1978 ground (89%) water (11%)

1) Note that U.S. Navy values are impact velocity changes, not initial impact velocities.

the civil values for initial longitudinal impact velocity. First, the civil all impact terrain sample is not limited to water impacts and the different characteristics of land impact terrains may affect the comparison. Second, examination of the accidents in the current sample whose longitudinal velocity exceeded 50 ft/s and caused the percentile difference reveals that these were primarily longitudinal impacts with shallow flight path angles. The 95th percentile value for a primarily longitudinal impact in the all terrain impact study was 72 ft/s (reference 6). This suggests that, for similar impact orientations, the initial longitudinal velocity values are comparable between the two civil studies.

Comparison of the 95th percentile vertical impact velocities again suggests that U.S. Navy water impacts are survivable at higher velocities. In the vertical direction, which may be considered the change in velocity for all three samples, the two civil samples compare most favorably with each other while the U.S. Navy value is considerably higher. The higher threshold of vertical velocity survivability found in the U.S. Navy study might be attributed to the generally heavier (and therefore larger) rotorcraft in the U.S. Navy study that would have more crushable structure available to absorb impact

energy. Of the 37 rotorcraft involved in significant survivable water-related impacts in the U.S. Navy sample, 33 had a maximum takeoff weight above 12,500 lbs, with 18 having a takeoff weight that exceeded 20,000 lbs. Additional reasons for the disparity might include more widespread use of safety equipment among U.S. Navy personnel, including good restraints and helmets. Energy-absorbing seats were not in use in the U.S. Navy helicopter accidents examined.

Lateral impact velocity values can be seen to vary widely between samples. This disparity probably results from the variation that can be found in estimating the impact yaw angle of a rotorcraft. Events such as the loss of a tail rotor and the resultant spinning of the aircraft can introduce wide scatter in the distribution of the yaw angle at impact. The lateral impact velocity, which is a function of yaw angle, is therefore affected by this variability. The accidents in the current effort whose lateral velocities exceeded the 10 ft/s value for the all impact terrain impact study all possessed yaw angles of 30 degrees or greater at impact, combined with either a substantial flight path velocity or a high yaw rate.

5.4 IMPACT SCENARIO DEVELOPMENT

An effective means of summarizing and further studying the results of this investigation was to establish scenarios that described the ways rotorcraft were typically found to impact the water surface. These scenarios may provide means of establishing new crashworthiness requirements since they define for this sample the velocities and orientations of the aircraft at impact, as well as the resulting occupant injury levels. Drawing upon the results of the accident reconstruction task, patterns in impact sequences were established and four impact scenarios established. Upon examining the impact parameters, including flight path angle, trends that supported three of these impact scenarios were found. The fourth scenario, cases with high yaw rate, was found in 6 of 7 cases identified to be already defined by the other three scenarios. These three impact scenarios were:

- Predominately high vertical impact velocity
- Predominately high longitudinal impact velocity (low flight path angle)
- Predominately high longitudinal impact velocity (high flight path angle)

The impact scenarios were defined by their kinematics. The first impact scenario, that of a high vertical velocity, was defined by the following criteria:

- flight path angle greater than or equal to 45 degrees
- vertical impact velocity component greater than the longitudinal velocity component

- roll angle between ± 20 degrees

- pitch angle between ± 20 degrees

The second impact scenario, accidents with a high longitudinal velocity and low flight path angle, was defined by these criteria:

- flight path angle between 0 and 20 degrees

- longitudinal impact velocity component greater than the vertical component

- roll angle between ± 20 degrees

- pitch angle between ± 20 degrees

- yaw angle between ± 20 degrees

The third impact scenario, cases with a high longitudinal velocity component and a high flight path angle, was defined by the following criteria:

- resultant angle greater than or equal to 45 degrees

- longitudinal impact velocity component greater than the vertical velocity component

- pitch angle between -20 degrees and -90 degrees

Table 5.6 presents the results of this impact scenario establishment task by showing the numbers and percentages of accident cases that were in each impact scenario

Table 5.6 Distribution of Survivable and Partially Survivable Accidents by Water Impact Scenarios

Scenario Type	Description	No. of Accidents	Percentage
1	predominantly high vertical velocity	25	69
2	predominantly high long. velocity (low FP angle)	9	25
3	predominantly high long. velocity (high FP angle)	2	6
	TOTAL	**36**	**100**
	OTHER	**24**	

category. It can be seen that the predominant impact scenario was that involving a high vertical velocity component and high flight path angle, an autorotation being a typical example. High longitudinal velocity components combined with a low flight path angle, represent 25 percent of the sample and was therefore another significant group. The third impact scenario, with both a high longitudinal velocity and flight path angle, represented 5 percent of the sample and represented the most significant impact scenario in terms of injury, as will be seen in section 6. Although numerically a small part of accidents considered, scenario three was presented as a contrast to land impacts where it would not be expected to be a survivable scenario (reference 6).

Review of the 24 civilian survivable and partially survivable accidents that did not satisfy the impact scenario definitions reveals that most had only one parameter that exceeded the defined magnitudes. It should be noted that nine of these 24 accidents could not be assigned to an impact scenario because the accident reports contained insufficient evidence to determine the impact parameters. Of the remaining 15 accidents, 12 were primarily longitudinal impacts with either a roll, yaw, or flight path angle that exceeded the $\pm$ 20 degree range. The other three accident cases were primarily vertical impacts with a either a roll, yaw, or flight path angle that exceeded the allowable ranges. Therefore, for those accidents whose impact parameters were known and did not satisfy impact scenario definitions, the impacts were typically similar to those that did satisfy the scenario definitions except for the attitude or flight paths of the aircraft.

5.5 POST-IMPACT SCENARIO DEVELOPMENT

As seen in the section on impact scenario development, the definition of scenarios provides a useful means of determining typical accident situations and improving the chances of survivability in such situations. Also, the water impact environment has been shown to present distinct post crash hazards to occupant survivability when compared to land impacts. Because scenarios are successfully used to define sets of frequently encountered impact conditions, defining scenarios for post-impact conditions seemed useful to describe how aircraft typical behave after impact. Based on the requirements for ditching certification (references 7, 8), the way to differentiate post-impact conditions for the occupants appears to be the time that the aircraft remained sufficiently upright to allow egress.

The criterion on which the two post-impact scenarios were established was the time the aircraft remained upright after impact. An immediate overturn was defined as the overturning of the aircraft within 90 seconds of touchdown and this describes post-impact scenario one. A delayed rollover was defined as the aircraft overturning after 90 seconds had elapsed since touchdown and this describes post-impact scenario two. A definition of "immediate" was chosen as 90 seconds for evacuation because it is the upper limit defined by FAR part 29.803 (reference 8) for emergency evacuation in a crash landing. It must be recognized that this regulation is defining evacuation time for ground impacts and does not necessarily refer to ditching situations. The part of the

data sample categorized according to post-impact scenario was limited to civilian survivable and partially survivable accidents. By looking at table 5.7 it can be seen that 82 percent of the total sample were cases of the rotorcraft overturning in 90 seconds or less, fulfilling post-impact scenario one. Another 18 percent were delayed overturn accidents. For 9 accidents, or 15 percent of the total sample, the time between touchdown and overturning could not be determined. It should be noted that the accidents considered for these post-impact scenarios include both controlled ditchings and water impacts.

Table 5.7 Distribution of Survivable and Partially Survivable Accidents by Post-Water Impact Scenarios

Scenario Type	Description	No. of Accidents	Percentage
1	Immediate Overturn	42	82
2	Delayed Overturn	9	18
	TOTAL	**51**	**100**
	OTHER	**9**	

The distribution of rotorcraft that remained upright for an appreciable amount of time can be seen to be relatively small. As previously discussed, it is inherently difficult to maintain rotorcraft in an upright attitude on a water surface with any significant wave height. Additionally, several rotorcraft were rolled intentionally, forcing the main rotor blades to strike the water and stop rotating, thereby facilitating escape. Unevenly deployed floats, other float problems, and lack of floats were the remaining known causes for overturning. Despite these problems, a significant number of rotorcraft, 9, remained upright. Upon investigating the wave height for aircraft that remained upright, however the average was found to be only 1 foot. It will be seen in section 6.3 that the occupants involved in "immediate overturns" experienced more occurrences of post-impact injury than did those involved in "delayed overturns". Also, section 7 will examine in detail the performance of aircraft flotation equipment intended to keep the downed rotorcraft upright long enough to allow occupant egress.

6. CHARACTERIZATION OF OCCUPANT SURVIVABILITY HAZARDS

A primary goal of this program was to identify hazards to occupant survivability in rotorcraft ditchings and water impacts. The approach used to achieve this goal was to record occupant injury data during the accident reconstruction task. The nature of this data was the type, cause, body location, severity, and relation to impact for each individual injury received by each occupant. This data was then categorized by cause to identify the main hazards to occupants in both the impact and post-impact environments. It should again be emphasized that the water crash environment is distinct from land and entails unique challenges to survivability. In establishing occupant survivability hazards, there was a need to examine both impact and post-impact conditions. The water impact surface differs from solid ground because the

challenge to occupant survivability does not end with successful egress from the aircraft. Upon exiting the aircraft the occupant is exposed to another set of potentially hazardous conditions.

This section examines both impact and post-impact occupant hazards, and discusses injury rates relative to the impact and post-impact scenarios defined in the previous section. The part of the data sample used in this analysis is limited to the civilian survivable and partially survivable accidents. The effect of restraint usage on occupant impact injury is examined. Also discussed is the effect of aircraft weight class on occupant impact injury. Post-impact hazards are explored, especially in relation to usage of personal flotation equipment. Throughout the discussions of occupant injuries, a set of standard terms are used to define the severity of the injuries. This set of terms is taken from the Abbreviated Injury Scale (AIS) developed by the American Association for Automotive Medicine (reference 12). This scale of occupant injury severity has been found useful in other similar programs in the past (reference 6) and therefore was again utilized for this effort. The numerical codes and definitions used to define the various AIS levels of injury severity are listed in table 6.1.

Table 6.1 Definition of Abbreviated Injury Scale (AIS) Codes

AIS Code	Definition
0	Not injured
1	Minor injury
2	Moderate injury
3	Serious injury (not life-threatening)
4	Severe injury (life-threatening, survival probable)
5	Critical injury (survival uncertain)
6	Maximum (untreatable - fatal)
7	Injured (unknown severity)
88	Unknown if injured

6.1 IMPACT INJURIES: TYPES, CAUSES, AND SEVERITY

Impact injuries were those injuries sustained by the occupants during the impact sequence. Table 6.2 summarizes the documented impact injuries for the civilian survivable and partially survivable accidents. It should be noted that the number of documented injuries does not correspond to the number of occupants and that a single occupant could receive multiple injuries. The injury causes were taken directly from the NTSB accident reports and these defined the object or mechanism (eg. accelerative force) which was determined by the accident investigator(s) to have caused the injury. From examination of the impact injury causes, types, and severity the impact hazards to occupant survivability may be determined.

The first cause of impact injury that will be discussed is accelerative force, which was the recorded cause of 21 of the 110 injuries (19 percent) documented for civilian survivable and partially survivable accidents. As would be expected, the types of injuries that were caused by accelerative forces affected the neck, thoracic spine (T-spine), and lumbar spine (L-spine). The types of spinal injuries varied from sprains and fractures to one occurrence of a severed brain stem. An aortal transaction was noted in one particularly severe accident by an occupant seated at the point of impact. All of these injuries indicate that the spine, and in one case the aorta, of these occupants were exposed to accelerative loads that exceeded human tolerance.

Injuries caused by occupant contact with various components of the airframe accounted for a further 16 of the 110 documented injuries (15 percent). These injuries can be seen in table 6.2 to range from minor lacerations caused by the occupant striking interior cabin surfaces to severe contusions and fractures resulting from occupant contact with the cyclic control. These various contact injuries can be attributed to flailing. Improper use or insufficient availability of proper body restraint allows the occupant's body, especially its extremities, to flail about freely at impact. This free movement allows the body to strike various components that may cause injury. The injuries whose cause was described as "other exterior objects" and "other" might also be considered flailing injuries when their descriptions are examined. The total number of impact injuries that might be attributed to flailing is then 25 of the 110 documented injuries (23 percent). Flailing, then, is the most frequent impact hazard, with accelerative forces being the second most frequent hazard.

The large number of injuries whose cause was documented as unknown, 62 of 110 (56 percent), do provide useful information when they are examined more closely. By looking at the types of injuries many, if not all could be attributed to flailing. Most of the fractures in this cause category were noted to be of the extremities, which again would support consideration of these injuries as flailing related.

Two other injury causes that were noted were a laceration sustained when an occupant was ejected from the aircraft and an abrasion caused by a restraint strap at impact. Ejection from the aircraft at impact is potentially an extremely hazardous situation, however this one injury is the only one attributed to this cause. The occurrence of this specific injury is discussed further in case study 3.

The type of restraint worn by occupants can have a significant influence on the frequency, type, and severity of impact injuries sustained by the occupants. The role of proper restraint in reducing flailing injuries has just been discussed. Therefore an examination of injury occurrences relative to occupant restraint usage was performed. This examination utilizes a rate of documented impact injuries per occupant relative to the type of restraint worn. Table 6.3 summarizes, for civilian survivable and partially survivable accidents, the results of this examination of occupant impact injury relative to

Table 6.2 Distribution of Impact Injuries by Severity, Type, and Cause

Injury Cause	No. of Documented Injuries	Injury Type and Severity
Accelerative Forces	21	2 severances, brain stem and aorta, both fatal 1 neck strain, minor 3 T-spine fractures, (2 moderate, 1 serious) 3 L-spine fractures, (2 minor, 1 serious) 3 L-spine sprains, all minor severity 1 T-spine dislocation, serious 8 unknown type injuries 2 neck, both serious 1 T-spine, unknown severity 4 L-spine, all minor 1 unknown location, fatal
Contact with Airframe:	(16 total)	
Windshield	1	1 minor lacerations, entire body
Windshield Frame	5	2 head contusions, minor and serious 1 leg laceration, minor 1 concussion severe 1 unknown head injury, severe
Sidewall	2	1 head contusion, severe 1 rib fracture, serious
Fuselage Framing/Structure	1	1 upper arm fracture, serious
Instrument Panel	4	1 facial laceration, minor 2 facial fractures, moderate and serious 1 unknown injury, fatal
Control Stick/Cyclic	3	2 chest contusions, serious and severe 1 rib fracture, severe
Contact With Other Exterior Objects	5	1 occupant - severe chest puncture, serious leg fracture, moderate femur fracture 1 occupant - serious leg laceration, serious thigh laceration
Ejected From Aircraft	1	1 occupant, head laceration, minor severity
Restraints-Seatbelt/Tiedown	1	1 abrasion, minor
Other	4	2 contusions, hip and knee, minor 1 laceration, minor 1 abrasion, minor
Unknown	62	16 lacerations 4 contusions 7 abrasions 13 fractures 1 concussion 2 dislocations 1 other 18 unknown
TOTAL	**110**	

restraint usage. From these results it can be seen that while occupants that wore shoulder harnesses and lapbelts appear to have received more impact injuries than those with lapbelt only (0.69 injuries/occupant versus 0.50 injuries/occupant) the better restrained occupants fared significantly better when looking solely at serious to fatal

impact injuries (AIS Severity 3 to 6). The impact injury rate for occupants with a lapbelt and shoulder harness drops by 0.43 to 0.26 injuries per occupant while that for lapbelt only drops by 0.21 to 0.29 injuries per occupant. Therefore, better restrained occupants wore found to benefit from the extra protection when considering more severe impact injuries.

Table 6.3 Occupant Impact Injury Rates Relative to Restraint Worn and Injury Severity, Civilian Survivable and Partially Survivable Accidents

Type of Restraint Worn	All Impact Injuries		Impact Injuries of AIS Severity 3 to 6	
	No. Impact Injuries/ No. Restrained Occupants	Impact Injuries Per Occupant	No. Impact Injuries/ No. Restrained Occupants	Impact Injuries Per Occupant
None	1/1	1.00	0/1	0.00
Lapbelt Only	47/93	0.50	27/93	0.29
Lapbelt and Shoulder Harness	43/62	0.69	16/62	0.26
TOTAL	**91/156**	-	**43/156**	-
Unknown Restraint	**19/48**	**0.40**	**2/48**	**0.04**

A relationship between impact injuries and aircraft weight class can also be found for civilian survivable and partially survivable accidents. The approach used to establish this relationship was similar to that used for relating occupant impact injury with restraint use. Rates were established for the number of impact injuries per occupant for each of the four aircraft weight classes. The results of this analysis are summarized in table 6.4. From this table it can be seen that occupants of weight class A and B had higher rates of impact injury per occupant than did weight classes C and D. One would expect that the rate of impact injury would increase as the weight (and size) of the aircraft decreased and this is what was observed. The injury rate experienced by weight class B occupants appears to violate this trend but can be explained by considering that all three civilian partially survivable accidents occurred to weight class B aircraft (see table 4.1). The more severe nature of these three accidents, all concentrated in aircraft weight class B, contributed to the relatively high rate of injury per occupant for this weight class. Of the 13 occupants involved in the partially survivable accidents, six were fatally injured and five were seriously injured.

6.2 POST-IMPACT INJURIES: TYPES, CAUSES, AND SEVERITY

Post impact injuries were those injuries that were sustained by the occupants after the rotorcraft had touched down. Table 6.5 summarizes the post-impact injuries whose causes were documented in the accident reports. Documentation was available for a total of 30 post-impact injuries from the civilian survivable and partially survivable accidents. As was stated in the impact injury section, the number of documented

Table 6.4 Occupant Impact Injury Rates Relative to Aircraft Weight Class and Injury Severity, Civilian Survivable and Partially Survivable Accidents

Aircraft Weight Class	All Impact Injuries		Impact Injuries of AIS Severity 3 to 6	
	No. Impact Injuries/ No. Occupants	Impact Injury Rate Per Occupant	No. Impact Injuries/ No. Occupants	Impact Injury Rate Per Occupant
A	14/31	0.45	0/31	0.00
B	79/106	0.74	39/106	0.37
C	16/50	0.32	5/50	0.10
D	1/17	0.06	1/17	0.06
TOTAL	**110/204**	**0.54**	**45/204**	**0.22**

injuries does not necessarily correspond to the number of occupants affected. In the presentation of the post-impact injury data, an indication of the number of occupants affected is given.

Examination of the types, causes, and severity of these injuries allows the definition of the post-impact survivability hazards. Drowning can be seen to be the most significant hazard, having contributed to 18 fatalities. It should be noted that while there were 26 fatalities in the civilian survivable and partially survivable accidents examined, drowning caused 18 fatalities. Exposure affected a further four occupants, and contributed to the death of one of these occupants. The specific events surrounding the exposure occurrences are discussed in case study 3. Three other occupants sustained lacerations of minor severity upon exiting the rotorcraft by contacting damaged components. An examination of the relationship between the drowning occurrences and personal flotation equipment is presented in section 7.2

Table 6.5 Distribution of Post-Impact Injuries by Cause, Type, and Severity

Injury Cause	Number of Documented Injuries	Injury Type and Severity
Inhalation of Water	19	18 occupants - drownings 1 occupant - water inhalation, serious
Exposure	7	1 occupant - fatal 3 occupants - sustained exposure effects to various parts of body
Contact with Airframe:	(2 total)	
Windshield	1	1 occupant - facial laceration, unknown severity
Doors/Hatches	1	1 occupant - facial laceration, minor severity
Unknown	2	1 occupant - hand and lower leg lacerations, minor severity
TOTAL	**30**	

In a previous investigation performed for all rotorcraft impact terrains (reference 6), post crash fire was noted to be the most dangerous hazard to the occupants.

In this study there were several significant points regarding fire and injury:

- There were no occurrences of post crash fire
- There were no thermal injuries

Post crash fire, the most dangerous hazard found in the previous investigation (reference 6), was not a factor in this sample. Although not recorded as part of accident reconstruction, it was noted that fuel spillage was reported in several cases.

6.3 INJURY OCCURRENCES FOR DEFINED SCENARIOS

To further describe the scenarios defined in this program, a discussion of the injuries relative to each scenario needs to be presented. The overall occupant injury levels for the three impact scenarios are summarized in table 6.6. The injury data presented in table 6.6 represents the overall injury level sustained by each occupant and includes the effects of both impact and post-impact factors on injury. It can be seen from table 6.6 that the percentage of seriously and fatally injured occupants is lowest for primarily vertical impacts and highest for primarily longitudinal, steep flight path impacts.

Injury frequency by post-impact scenario is presented in table 6.7 and again, it includes both impact and post-impact effects on overall occupant injury level. This table shows that the frequency of injury is much higher for cases of immediate overturning than it is for delayed overturning. A total of 30 percent of occupants involved in immediate overturns were seriously or fatally injured compared to only 9 percent receiving such injuries in delayed overturns. The higher percentage of seriously and fatally injured occupants for immediate aircraft overturns includes both impact and post-impact injury effects. This higher percentage may also reflect the fact that the impact kinematics that contributed to the immediate overturning also contributed to the higher frequency of injury.

Table 6.6 Distribution of Injuries by Impact Scenario

Scenario Type	Scenario Description	Number of Occupants Per Overall Injury Level			Total on Board	Percentage of Fatally/Seriously Injured Occupants
		Fatal	Serious	Minor		
1	predominately high vertical velocity	5	11	11	97	16.5
2	predominantly high long. velocity (low FP angle)	5	3	10	37	21.6
3	predominantly high long. velocity (high FP angle)	5	4	2	11	81.8
TOTAL					**145**	

Table 6.7 Distribution of Injuries by Post-Impact Scenario

Scenario Type	Scenario Description	Number of Occupants Per Overall Injury Level			Total on Board	Percentage of Fatally/Seriously Injured Occupants
		Fatal	Serious	Minor		
1	Immediate Overturn	23	20	32	142	30.3
2	Delayed Overturn	1	3	3	44	9.1
TOTAL					186	

7. EVALUATION OF AIRCRAFT AND OCCUPANT FLOTATION PERFORMANCE

One of the main goals of this program was to evaluate aircraft and occupant flotation performance. This equipment is critical for occupant post crash survivability in the water environment. Current FAA regulations already contain ditching requirements for rotorcraft (references 7, 8, 10, and 13). The four major areas that must be addressed to obtain FAA ditching certification are:

- rotorcraft water entry
- rotorcraft flotation and trim
- occupant egress
- occupant survival

Analysis was conducted on the accident data in all four of these areas. Consideration was also given to rotorcraft water impacts that did not satisfy the FAA definition of a ditching. The post crash characteristics of these impacts needs to be examined as well. All data presented and analyzed in this section are from civilian survivable and partially survivable accidents.

7.1 AIRCRAFT FLOTATION PERFORMANCE

The first area considered by rotorcraft ditching certification is the water entry of the rotorcraft. The velocity and attitude with which the rotorcraft enters the water can directly affect the flotation and trim of the rotorcraft after touchdown. Ditching certification requirements specify the range of impact parameters for ditching performance (references 7,8). The impact parameters and their values for normal and transport category rotorcraft can be summarized as follows:

- Longitudinal Velocity $\leq$ 50 ft/s
- Vertical Velocity $\leq$ 5 ft/s

- Yaw Angle $\leq$ 15 degrees
- Seastate $\leq$ 8 ft. wave height
- Aircraft landing forced by power loss, with all other controls/systems functioning properly

After entering the water under the above conditions the rotorcraft is expected to remain sufficiently upright and in adequate trim to permit occupants to leave the rotorcraft and enter life rafts.

To maintain the required attitude and trim after water entry, rotorcraft can be equipped with emergency flotation devices. These devices may be mounted either on the skids or on the fuselage and are for use in ditching. These devices are normally inflatable and are stowed in a compact form, only being armed and inflated when water contact is imminent. The purpose of these flotation devices is to keep a rotorcraft upright and afloat. Their effectiveness, however, is made difficult by the rotorcraft's basic design. The engines and transmission, the heaviest components on the aircraft, are typically mounted high. Thus, the rotorcraft has a high center of gravity and a natural tendency to invert when in the water unaided by floats, or when in significant wind and waves, even with emergency flotation successfully deployed. This section examines the performance of rotorcraft flotation equipment as indicated by this investigation.

Aircraft flotation and trim behavior was examined for those rotorcraft that impacted the water surface within the above impact parameter ranges and were equipped with floats. The pitch and roll angles were limited to $\pm$ 15 degrees as a further criterion. The performance of these rotorcraft and their floats provides an indication of how rotorcraft performed relative to current requirements.

- 4 rotorcraft impacts satisfied ditching conditions
- 3 of these rotorcraft were equipped with floats
- 2 of the 3 float-equipped rotorcraft had floats that survived impact
- Both of the rotorcraft with floats that survived impact overturned immediately

These results show that the floats for rotorcraft in this sample were generally not effective in keeping the aircraft upright in ditching conditions. In considering these results, however, the relatively small number of ditching cases must be kept in mind.

The wave height encountered by a downed rotorcraft greatly affects whether the rotorcraft can maintain an upright attitude once it has touched down. Wave heights are

categorized by the FAA in their regulations. This classification is from the World Meteorological Organization (reference 10) which assigns a range of wave heights and wind speeds to a list of ten sea states. FAA regulations currently require that sea state four be considered "reasonably probable water conditions" and that it be used as criteria for the adequacy of rotorcraft ditching equipment (reference 10, 13). Table 7.1 shows the sea state definitions and the distribution of accidents by sea state. The predominant sea states encountered were sea state two (wave height of 1/3 to 1 2/3 feet) and sea state three (wave height of 1 2/3 to 4 feet). No sea states higher than five were encountered. It is of interest that 94 percent of all sea states encountered were sea state 4 or below.

Table 7.1 Distribution of Sea States Encountered by Rotorcraft

Sea State Encountered by Downed Rotorcraft *	Number of Rotorcraft	Percent of Rotorcraft
0, 1 (0 to 0.3 ft)	5	8%
2 (0.3 to 1.7 ft)	21	36%
3 (1.7 to 4 ft)	18	31%
4 (4 to 8 ft)	11	19%
5 (8 to 13 ft)	4	7%
6 (13 to 20 ft)	0	0%
TOTAL	**59**	**100%**
Unknown	**1**	

* Sea states defined according to World Meteorological Organization Definition (reference 10)

The post-impact characteristics of rotorcraft that did not impact the water surface within the FAA ditching definition requirements also require examination. There were a total of 56 cases that were survivable and partially survivable water impacts. The performance of rotorcraft flotation equipment in these 56 cases can be summarized as follows:

- 32 rotorcraft in water impacts were float-equipped
- 13 of the 32 float-equipped rotorcraft had floats that were activated and survived impact intact
- 8 of the 13 rotorcraft with floats that survived impact overturned immediately

Of these 56 cases, 21 satisfied all of the impact and pilot control conditions of the ditching definition but had vertical velocities that exceeded 5 ft/s. These might be

considered to be "almost ditchings". The impacts in these accidents were more controlled than the remainder of the water impact sample and therefore the flotation performance in these cases should be examined separately. The performance of flotation equipment in these 21 cases can be described as follows:

- 10 rotorcraft in "almost ditchings" were float-equipped
- 6 of the 10 float-equipped rotorcraft had floats that were activated and survived impact intact
- 3 of the 6 rotorcraft with floats that survived impact overturned immediately

Rotorcraft flotation devices are designed to function under ditching conditions, not water impact conditions, and therefore the deficiencies shown in the sample of 56 water impacts are not surprising. Even if a rotorcraft's floats in this category survive impact an erratic impact sequence could contribute to the overturning of the vehicle. However, when considering the flotation equipment performance in the "almost ditching" category, some observations regarding flotation performance may be made. Because these rotorcraft, although impacting harder vertically than ditchings, landed in a fairly controlled manner, it would be expected that if the floats survived the impact the rotorcraft would still tend to remain upright. Immediate overturning was still observed for this category, however, with three of the six rotorcraft with intact floats overturning immediately.

During the course of the accident reconstruction task, several reasons were noted for the failure of the floats to be activated. These reasons included system malfunction and preoccupation of the pilot with the requirements of making an emergency landing. The relatively low number of floats that survived impact partially reflects the more rigorous landing parameters that existed in some of these water impact cases.

The relationship between rotorcraft flotation deployment, for both ditchings and wate impacts, and the 18 drowning occurrences deserves examination. In 15 of the 18 drownings that occurred, the occupants were on float-equipped aircraft. Also, it should be noted that 5 of these 15 drowning victims were occupants on rotorcraft whose floats were never even armed. None of the rotorcraft in which drownings occurred remained upright for more than approximately one minute. In section 5.5, post-impact scenarios were defined based on the time that the rotorcraft remained upright. When considering the occurrences of drowning relative to the time the rotorcraft remained upright, one can see that post-impact scenario one, immediate overturn of the rotorcraft, was more hazardous for the occupants primarily from post-impact causes.

To lessen any bias created by examining higher severity accidents for aircraft flotation performance, the data identified through the Accident/Incident Data System (AIDS) were reviewed. These records were examined to evaluate the performance of aircraft

flotation in accidents/incidents which were not documented in the NTSB reports included in the main sample and were therefore presumably less severe. A total of 37 accidents/incidents were identified that were not included in the NTSB sample for the years being investigated. These accidents/incidents all involved either ditchings or water impacts but the only documentation available for them were the AIDS briefs. Of these 37 accidents/incident records, only four made any reference to the use of aircraft flotation equipment. These four flotation references all described successful deployments of aircraft flotation.

7.2 PERSONAL FLOTATION EQUIPMENT PERFORMANCE

In addition to aircraft flotation equipment, personal flotation equipment is also a critical aid to successful occupant survival. Its importance in this sample is magnified when considering that the rotorcraft frequently did not remain upright or afloat very long after impact. The occupants must then rely on auxiliary means of keeping themselves afloat until rescue. After examining the post-impact injury information in section 6.2 regarding the most frequent types and causes, it can be seen that drowning was the most significant and frequent post-crash hazard. Several factors contribute to drowning after a water impact:

- the shock of a severe impact can impair occupant activity
- impact injuries can limit occupant performance
- obstructed exits or stuck restraints may entrap occupants
- low water temperature can reduce bodily activity
- a rough sea state may tire the crash survivors

The egress conditions experienced by the occupants is important to consider because these conditions may impact the effective utilization of personal flotation equipment. Table 7.2 illustrates the distribution of the aircraft's buoyancy status at the time the occupant exited the aircraft. Note that most occupants had to escape from an aircraft that was at least partially submerged. This again points out the natural instability of a rotorcraft in a water environment. Occupant inaction as a result of psychological factors was observed in the data studied. In several cases occupants froze in their seats upon impact and, though not injured by the impact forces, they became fatalities by drowning. Difficulty in egress because of an occupant's inability to undo his or her restraint was also noted in several cases. A specific occurrence of this difficulty is described in case study 5.

Table 7.2 Distribution of Aircraft Buoyancy Status at Time of Occupant Egress

Aircraft Buoyancy Status At Time of Occupant Egress	Number of Occupants	Percent of Occupants
Floating	34	17%
Sinking	71	36%
Partially Submerged	66	33%
Resting on Bottom	12	6%
Other	16	8%
TOTAL	**199**	**100%**
Unknown	**5**	

The availability, use, and performance of personal flotation was examined to assess this important survival equipment. The total number of occupants that had some form of personal flotation available for their use was 111 out of a total of 204 occupants in the civilian survivable and partially survivable sample. Of the 111 occupants that had personal flotation available, 86 are known to have used it. The main results of the personal flotation assessment is summarized in figure 7.1. There are several points that should be discussed about the data in this figure. The first is that the seat cushions that were used as personal flotation devices were not designed as such, rather they were used in desperation. Also, 23 of 24 occupants used a life raft while using some other form of flotation device at the same time. There were several incidents in which inflatable vests did not work because of occupant problems with donning them or inflating them.

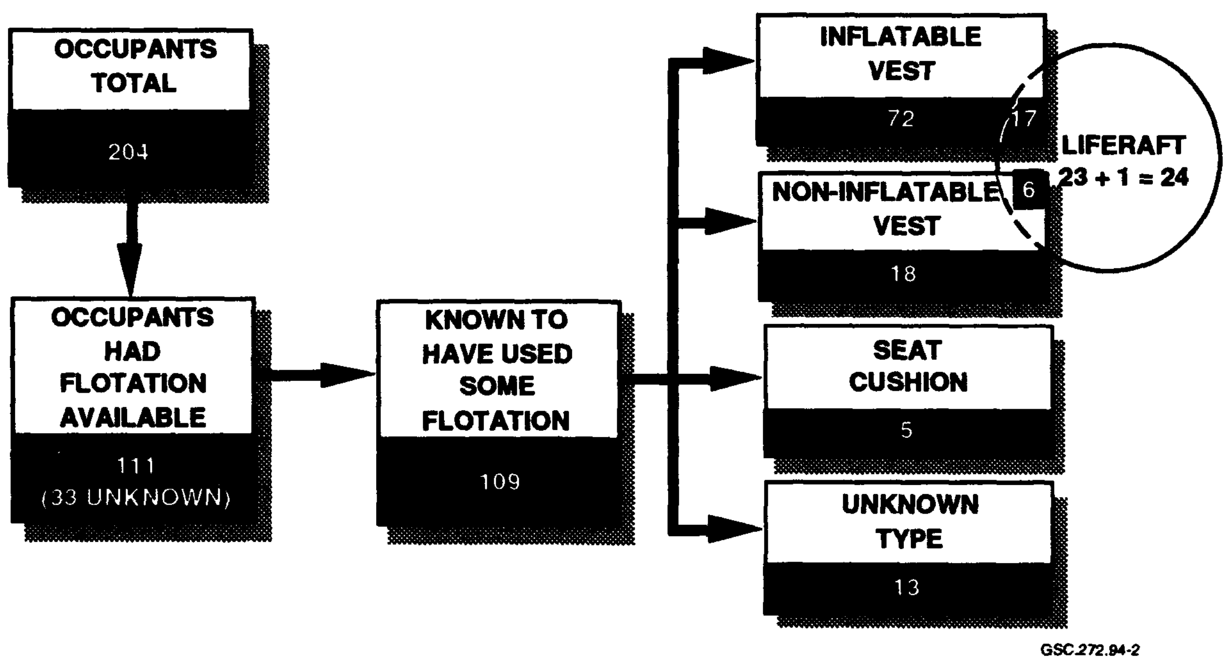

Figure 7.1 Distribution of the Availability, Use, and Performance of Personal Flotation Equipment

Federal regulations require that the rotorcraft's flotation equipment keep the rotorcraft sufficiently afloat and in adequate trim to allow the occupants to leave the rotorcraft and enter life rafts (references 7,8). Only 24 of the total 204 occupants, however, were noted to have made use of a life raft. This is a significant discrepancy that reflects life raft availability and usage problems.

Because of the predominance of drowning as a hazard in this sample, as well as the need to evaluate flotation equipment performance in this program, a closer look was made to determine the role of personal flotation equipment in the drowning occurrences. The following findings were made:

- Of the 18 drowning victims, 10 had personal flotation available, five did not, and its availability is unknown for three occupants.

- Of the 10 drowning victims with flotation equipment available, only five used it.

- Of the five drowning victims that used personal flotation equipment, two experienced malfunctioning equipment.

Therefore it can be seen that problems with the availability, use, and performance of personal flotation equipment were all contributing factors in the 18 drownings. Additional factors that were noted during the accident reconstruction process included heavy seas, egress difficulty, and psychological shock. Several occupants were described as "frozen" in their seats and these occupants drowned as a result while other occupants on board with them egressed safely.

Records were made of the time occupants were in the water after the aircraft had touched down and the distribution of these results can be found in table 7.3. A majority of occupants were in the water for 30 minutes or less (77 percent). There was, however, another significantly large group of people who were in the water for much longer. The distribution of the time the occupants were in the water illustrates the importance of effective personal flotation equipment because significant numbers of people remained in the water for an appreciable amount of time before rescue. The

Table 7.3 Distribution of Occupant Time in the Water

Occupant Time in Water (minutes)	Number of Occupants	Percent of Occupants	Cumulative Percent of Occupants
0 - 15	71	47.02%	47.02%
16 - 30	45	29.80%	76.82%
31 - 60	9	5.96%	82.78%
61 - 120	26	17.22%	100.00%
TOTAL	**151**	**100.00%**	
Unknown	**53**		

occupant time in the water is a reflection of whether or not the pilot notified appropriate authorities of his emergency, as well as the proximity and effectiveness of rescue teams responding in that situation. Poor performance of Emergency Location Transmitters (ELT's) was noted during accident reconstruction. Although not recorded as part of the data, it was noted that ELT's frequently did not work. It is understood that improvements to ELT performance are expected under currently proposed regulations.

8. CASE STUDIES

The reason for including several case studies was to enhance the characterization of the rotorcraft water impact sequence. It was felt that a narrative format would be effective in bringing out peculiar aspects that could not be adequately covered in statistical categorizations. The case studies presented herein describe a variety of crash sequences that highlight the following areas: impact velocities and attitudes, level of survivability, aircraft damage, egress conditions, and flotation performance. Photographic documentation is presented where available, especially of the occupiable volume of the rotorcraft and to highlight any damage experienced, to better convey the effects of water impact on the aircraft structure and its occupants. The following case studies demonstrate the unique aspects of the rotorcraft water impact sequence as revealed by this investigation.

8.1 CASE STUDY 1

8.1.1 Introduction. This case study documents an accident involving an aircraft from weight class A impacting onto a salt water surface. The accident occurred in daylight with Visual Meteorological Conditions (VMC) prevailing. The wind speed was recorded at four kts. and air temperature at 41° F. The impact surface was recorded as rough with swells of approximately eight feet (sea state four).

Because of the nature of the impact, the accident is included in impact scenario one (predominantly vertical, flat impact). This accident also falls within the definition of post-impact scenario one (immediate overturn). In this accident, there were five people on board; four received minor injuries and one was not injured.

8.1.2 Accident Characteristics. The accident initiated approximately 30 sec. after lift off from an oil platform. At approximately 150 - 200 ft. above the water surface with an airspeed of 30 - 40 kts., the engine failed for unknown reasons. The failure followed an observed 10 percent torque bounce one to two seconds earlier. The low RPM audio warning was heard by pilot and passengers immediately previous to the engine out warning.

The pilot initiated an autorotation, during which a mayday call was transmitted and the emergency floats were activated. The pilot claimed to have pulled full collective to flare the aircraft just prior to touchdown. The aircraft impacted the water hard with the

emergency floats partially inflated. It is believed that there may not have been enough altitude at the time of engine failure to allow recovery of sufficient rotor RPM to facilitate a soft touchdown. It was also noted that the main rotor struck the tail boom upon impact which would support a low rotor RPM conclusion. Witness statements indicated that the aircraft impacted the top of a swell and subsequently became inverted in a left-rolling, nose-over motion. The floats continued to inflate and the aircraft was floated in an inverted attitude as the occupants egressed.

8.1.3 Impact Conditions. The accident was reconstructed using the methodology presented in Appendix C. The impact conditions developed during the reconstruction are given below:

- Velocity Vectors:

Vertical	30 ft/s
Longitudinal	6 ft/s
Lateral	0 ft/s

- Flight Path Angle: 80°

- Attitude:

Roll	0°
Pitch	0 - 5 ° (nose up)
Yaw	0°

8.1.4 Damage. The aircraft in this case was recovered and noted to have sustained substantial damage. Major aircraft damage that was not attributed to recovery efforts is listed below:

- Tail boom severed in two places, fore and aft of stabilizer.
- Tail rotor blades, hub assembly, gear box, and aft-most section of tail boom missing (figure 8.1).
- Damage to one main rotor blade because of striking tail boom.
- Both chin bubbles broken (figure 8.1).
- Both forward windshields missing (figure 8.1).
- Left passenger door missing (figure 8.2).
- Right passenger door deformed (figure 8.1).

Figure 8.1 Case Study 1, Right Side View of Aircraft

Figure 8.2 Case Study 1, Left Front View of Aircraft

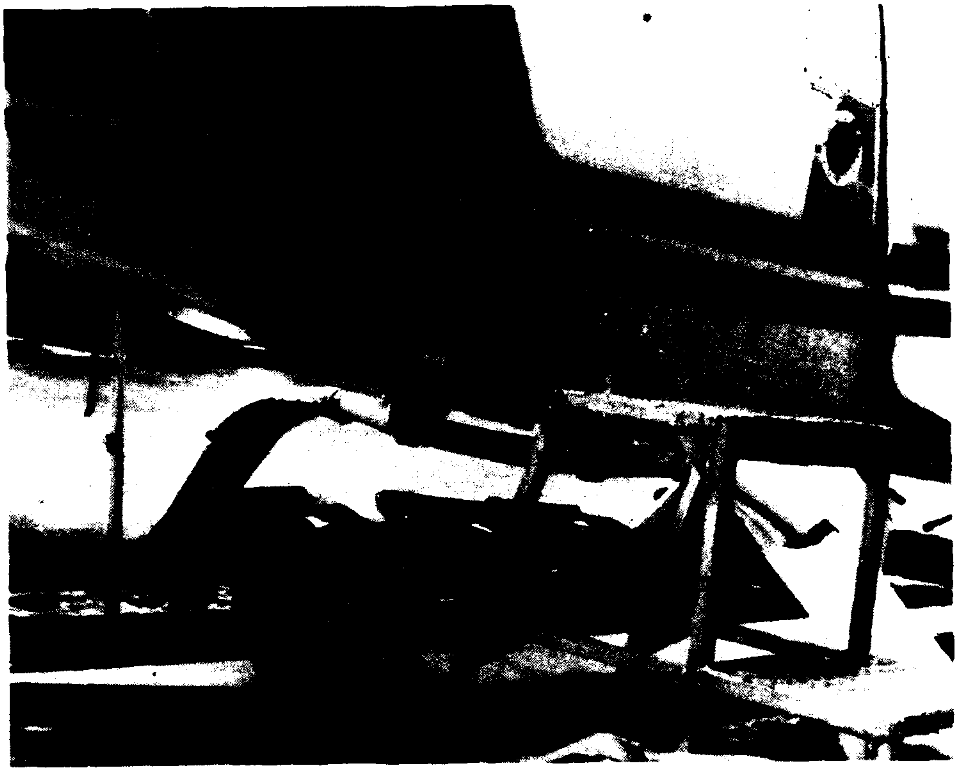

Figure 8.3 Case Study 1, Lower Right View of Aircraft

- Airframe cracked three ft. forward of aft cross-tube (figure 8.3).
- Aft crosstube fairings crushed (figure 8.3).
- Cabin roof displaced three in. toward floor (figure 8.2).

There was no damage to the skid-mounted emergency floats noted in the accident report.

8.1.5 Injury and post-impact Survivability. Five occupants were on board this aircraft during the accident. Four of the five were reported as sustaining minor injuries; the fifth was reportedly not injured. All of the occupants were in the water for approximately 15 minutes before rescue. Personal flotation and a life raft were available in the aircraft before the accident. However, it is not known if they were used by any of the occupants. The specific injuries that the occupants sustained in this accident as well as each occupant's post crash survivability aspects are discussed below:

- Pilot - right front. This occupant was reported to have sustained minor injuries to the back and/or spine. The specific type of injury is unknown. The occupant reportedly was wearing both lap belt and shoulder harness restraints. The cause of the injuries was attributed to whole-body accelerative loading. The occupant's

path of egress was not noted. The most likely paths of egress include the broken out front windshields or one of the front doors.

- Pax - left front. This occupant was reported to have sustained minor injuries to the spine. The injuries were described as two compression fractures of the spine. The cause of the injuries was recorded as whole-body accelerative loading. The occupant stated: "..unlatched my seat belt.."; therefore, restraint use by this occupant is assumed. The injuries sustained and the lack of flailing-related injuries may further indicate that the occupant was using both lap belt and shoulder harness restraints. This occupant further stated that his/her egress was active and through the windshield. Note that the impact was believed to have caused both windshields to be broken/displaced from their mounting frames.

- Pax - left middle. This occupant was reported to have sustained minor injuries to the back/spine region. The specific type of injuries was not reported, nor was the occupant's restraint usage. The cause of the injuries was attributed to whole-body accelerative loading. No information was recorded about the occupant's egress. The large left passenger door, immediately next to this occupant, was reported as missing. This door, whether closed, open, or missing after impact, could be a likely path of egress for this occupant.

- Pax - left rear. This occupant was reported to have sustained minor injury to the back/spine region. The cause of the injuries was attributed to whole-body accelerative loading. The occupant's usage of restraint(s) was not recorded. However, the occupant stated that he/she assumed a 'crash position' prior to impact. It is unknown what specific crash position was assumed or if it was appropriate for the helicopter impact environment. This occupant claimed to have egressed through a window. However, it is possible that the 'window' was the opening where the left passenger door previously had been (providing it had been torn off during impact rather than by the following wave action). This occupant was seated immediately next to this door.

- Pax - right rear. This occupant was not injured. The occupant's use of restraint(s) was not recorded. The occupant's egress also was not recorded. The left passenger door seems to be the most likely path of egress, since the right passenger door was reported as deformed and apparently was not opened following the impact.

8.1.6 Discussion. This accident is typical of impact scenario one as defined in section 5.4. The helicopter impacted the water relatively flat at predominantly vertical velocity. The level and type of injuries and aircraft damage suggests that the water impact conditions were approaching the upper limit of survivability for weight class A. Four of the five occupants sustained some degree of minor back injuries. The more serious of these were two spinal compression fractures in one occupant. In spite of the injuries,

the occupants were able to egress the aircraft without aid. The airframe was substantially damaged, but maintained a survivable volume. Although the aircraft inverted immediately, the emergency floats kept the aircraft at the surface which greatly enhanced the potential for survivability.

It was noted that the floats were not fully inflated at the time of impact. This compares with similar accidents (weight class A) examined under this investigation, where the floats were fully inflated upon impact and were torn off by hydrodynamic forces upon impact. This perhaps can support the use of immersion type sensors for float deployment.

8.2 CASE STUDY 2

8.2.1 Introduction. This case study describes an accident involving an aircraft from weight class C impacting onto a fresh water surface. This accident occurred in daylight with Visual Meteorological Conditions (VMC) prevailing. The wind speed was recorded at 10 kts and air temperature at 68 deg F. The impact surface was recorded as calm with an average estimated wave height of one foot (sea state two).

Because of the impact parameters, this accident falls within the definition of impact scenario two (predominantly longitudinal, shallow flight path angle). The post-impact behavior of the rotorcraft in this accident falls within the definition of post-impact scenario two (delayed overturn). In this accident, there were six people on board: three received minor iniuries and three were not injured.

8.2.2 Accident Characteristics. This accident began when the rotorcraft experienced a loss of tail rotor control (signaled by a sharp 30-40 ° right yaw) while in cruise at an altitude of 2000 ft. and an airspeed of 150 kts. This event took place during an overwater flight. Descent took place at a sink rate of 5 ft/s. The right yaw condition was slowed by hard, left pedal application but it remained present throughout the controlled descent. A mayday call was transmitted and received by air traffic control during the descent, which facilitated rescue.

The resultant impact velocity was estimated by the crew to be 40 to 50 kts. (about 76 ft/s) with a flight path angle of about 4-5°. The impact attitude was estimated to be 5° nose up with 0° roll and yaw. The aircraft impacted, skimmed the water surface, then impacted again, yawing 180° to the right. The first touchdown was described as "hard" and may account for three passengers reporting minor back aches in their upper torso region. The aircraft finally came to rest at a 10 degree list to the left.

This rotorcraft was equipped with four fuselage mounted floats, three of which were successfully deployed manually at 73 kts. airspeed prior to touchdown. According to a passenger, the aircraft submerged to a depth of one foot below the surface and then stabilized. The aircraft remained upright for about 15 minutes, slowly filling with water

and listing to the left until it became inverted. Despite overturning the aircraft remained afloat A passenger also noted that the floats didn't appear to be holding up the aircraft after it had inverted because he saw no tension in the four float cables.

8.2.3 Impact Conditions. The accident was reconstructed using the methodology presented in Appendix C. The impact conditions developed during the reconstruction are given below:

- Velocity Vectors:

Vertical	12 ft/s
Longitudinal	75 ft/s
Lateral	0 ft/s

- Flight Path Angle: 4°

- Attitude:

Roll	0°
Pitch	5° (nose up)
Yaw	0°

8.2.4 Damage. The aircraft in this case was recovered. Substantial damage to the aircraft was sustained due to a combination of the impact, seabed corrosion, and the recovery operation. The water impact damage reported was separation of the tail rotor blades hub, gearbox and drive components.

8.2.5 Injury and post-impact Survivability. There were six occupants on board; three received minor injuries and three were not injured. The injuries and the post-impact survivability aspects for each occupant are discussed below.

- Pilot - right front. This occupant was restrained with a lapbelt and shoulder harness and was not injured. Egress for this occupant was reported to be through the right front door

- Pax - left front. This occupant was restrained with a lapbelt and shoulder harness and was not injured. Egress for this occupant was reported to be through the left front (co-pilot) door.

- Pax - left rear. This occupant wore a lapbelt only and was not injured. Egress for this occupant was reported as through the right front door.

- Pax - right middle. This occupant was restrained with a lapbelt only and complained of minor back pain. The left front or co-pilot's door was reported as the path of egress for this occupant.

- Pax - left middle. This occupant was restrained with a lapbelt only and reported minor back pain. This occupant was reported to have egressed through the right front door.

- Pax - right rear. This occupant complained of minor back pain and wore a lapbelt only. This occupant was reported to have egressed through the right front door.

Life vests were available and used without problems by all occupants. The occupants exited without difficulty approximately 10 minutes after the aircraft had touched down. The aircraft was upright during this evacuation. The occupants stood on the belly of the aircraft after it overturned and awaited rescue; they spent 30 minutes in the water after impact.

8.2.6 Discussion. Impact scenario two (high longitudinal velocity, shallow flight path angle) is well portrayed by this case. The only traumas suffered were minor back aches which show that the whole-body accelerative forces were within human tolerance limits and, in addition, there was no noted significant structural damage to the cabin.

This case demonstrates the expected performance of helicopter flotation devices. In this shallow run-in sequence they were deployed well before touchdown and survived impact. There was debate among the occupants whether one of the four floats, the front port float, inflated fully. Unequal flotation may have contributed to the overturning of the aircraft.

8.3 CASE STUDY 3

8.3.1 Introduction. This case study describes an accident involving an aircraft from weight class B impacting onto a salt water surface. This accident occurred in darkness with Visual Meteorological Conditions (VMC) prevailing. The wind speed was recorded at 13 kts., gusting to 20 kts., and air temperature was recorded at 35 deg F. The impact surface was recorded as choppy with wave heights of up to two feet (sea state three).

Because of the impact parameters, this accident falls within the definition of impact scenario two (predominantly longitudinal, shallow flight path angle). The post-impact behavior of the rotorcraft in this accident falls within the definition of post-impact scenario one (immediate overturn). In this accident, there were four people on board: one received fatal injuries, two received serious injuries, and one received minor injuries.

8.3.2 Accident Characteristics. The pilot of this aircraft apparently lost horizontal reference while flying above the water in darkness and the impact came as a total surprise. The pilot stated that he had been flying at 100 mph and then reduced his altitude to below 500 ft. to improve visibility. The aircraft impacted the water, nosed over, and then became inverted. The rotorcraft was equipped with skid-mounted floats which inflated upon impact; the left float ruptured and separated.

8.3.3 Impact Conditions. The accident was reconstructed using the methodology presented in Appendix C. The impact conditions developed during the reconstruction are given below:

- Velocity Vectors:

Vertical	7 ft/s
Longitudinal	118 ft/s
Lateral	0 ft/s

- Flight Path Angle: 4°

- Attitude:

Roll	0°
Pitch	0 - (–) 5° (nose down)
Yaw	0°

8.3.4 Damage. An unknown amount of damage was done during recovery of the wreckage. The post-recovery damage of the aircraft was recorded as follows:

- Both front chin bubbles and windshields destroyed (figure 8.4).
- Both front doors and posts torn away (figure 8.5).
- Left front seat and pedestal ripped out (figure 8.5).
- Tail boom broken off (figure 8.6).
- Main rotor blades and head assemblage broken off (figure 8.4).
- Transmission displaced forward and partially separated (split top of fuselage) (figure 8.4).
- Extensive damage to left side of cockpit and cabin and relatively minor damage to right side (figures 8.4, 8.7).

- Major distortion to pilot's seat (pan frame distorted forward and down)
- The left skid-mounted float ruptured and separated at impact.

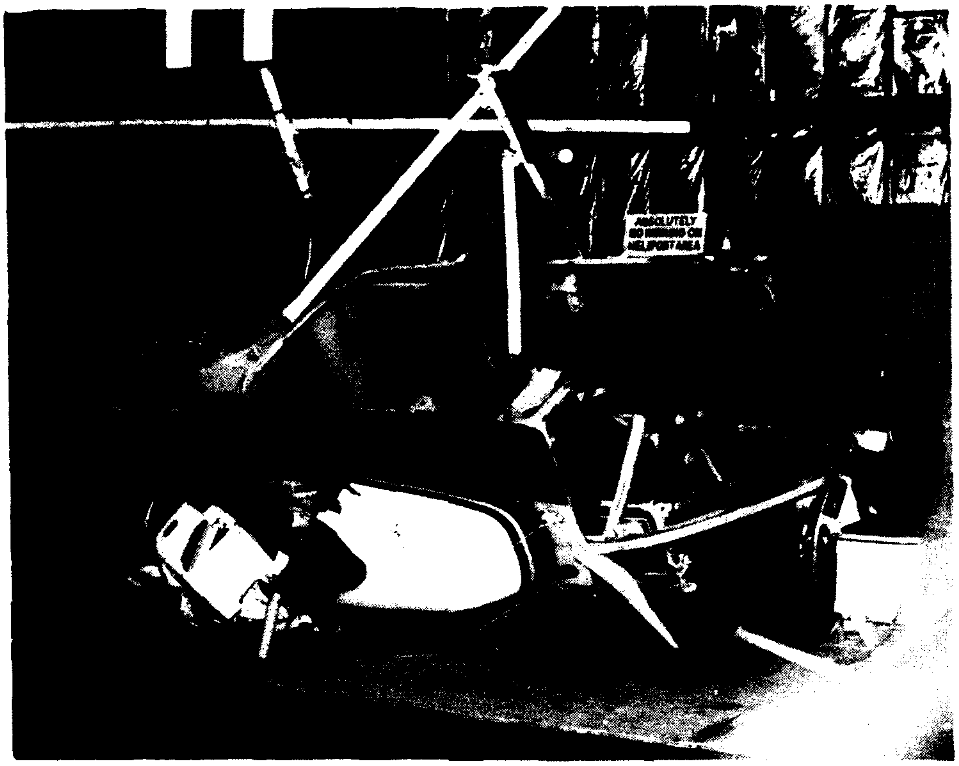

Figure 8.4 Case Study 3, Top View of Aircraft

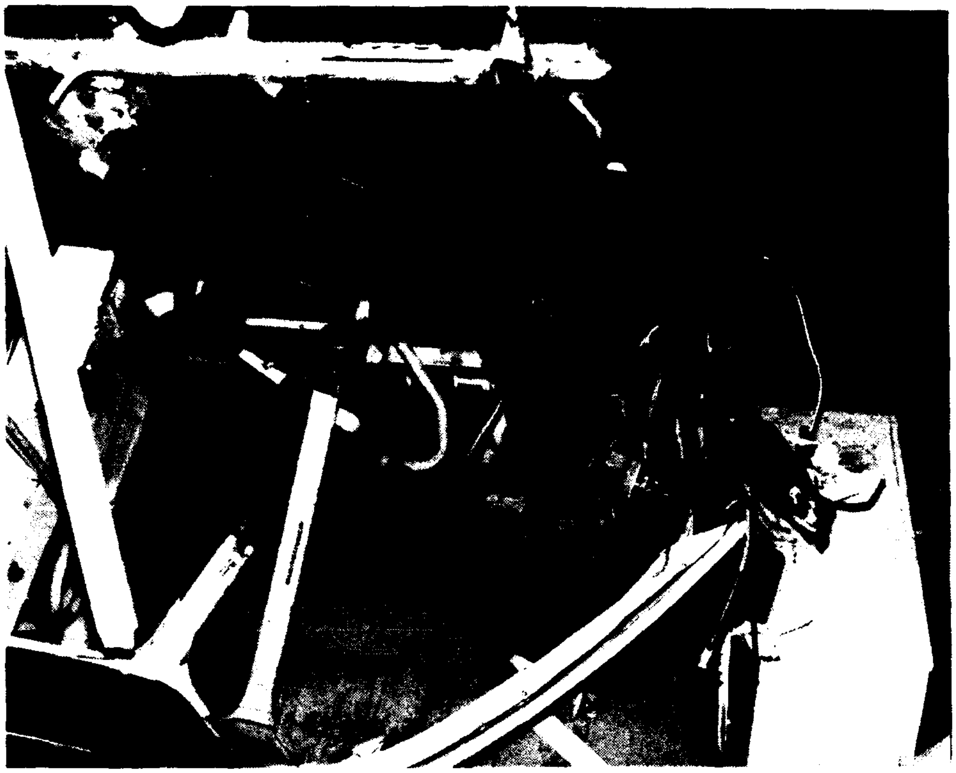

Figure 8.5 Case Study 3, Left Front View of Aircraft

Figure 8.6 Case Study 3, Rear View of Aircraft

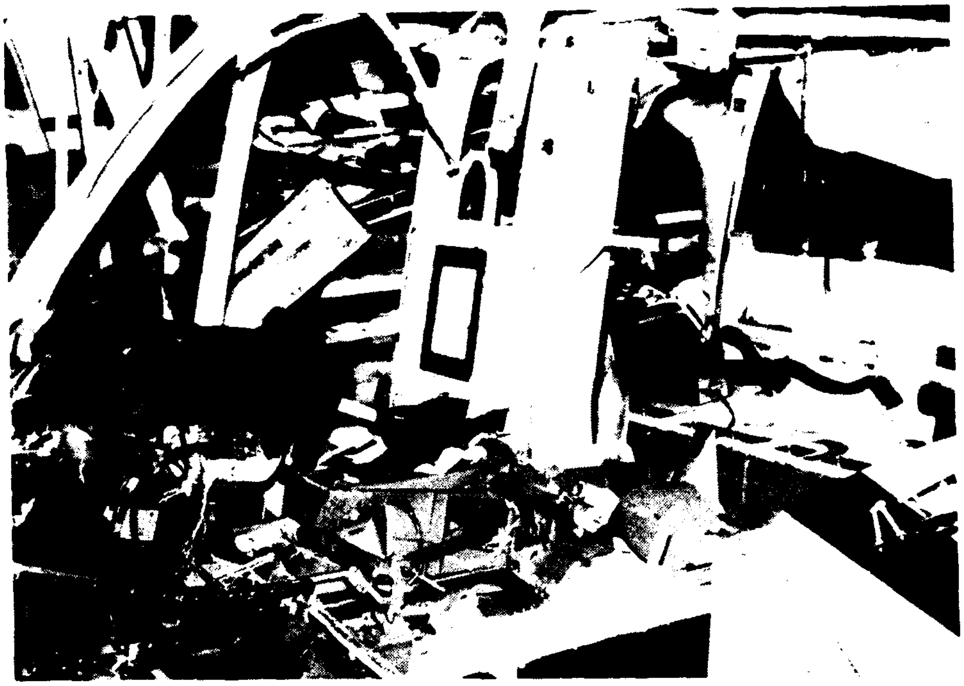

Figure 8.7 Case Study 3, Left View of Cockpit and Cabin

8.3.5 Injury and post-impact Survivability. Four people were on board at impact with one fatality, two seriously injured and one receiving minor injuries. The injuries and the post-impact survivability aspects for each occupant are discussed below.

- Pilot - right front. This occupant was restrained with lapbelt and shoulder harness and was reported to have sustained minor injuries. The occupant suffered from exposure and also stated that he was treated for an abrasion on his right leg. A path of egress was not noted because the occupant reported that after releasing his restraint he found himself on the surface next to the aircraft. The most likely path of egress could have been the right windshield.

- Pax - left front. This occupant became a fatality from hypothermia and received a cut over his right eye. Restraint use for this occupant is not known with certainty, however another passenger stated that this occupant's shoulder harness was not fastened. This occupant was ejected from the aircraft upon impact. Examination of the cabin wreckage revealed the right portion of the seatbelt still attached undamaged to its mounting point.

- Pax - left rear. Restraint for this occupant was lapbelt only. This occupant sustained serious injuries resulting from a contusion to the leg and a fracture of the thoracic spine. The occupant also suffered from the effects of exposure.

- Pax - right rear. Restraint for this occupant was lapbelt only. This occupant sustained serious injuries resulting from exposure effects.

All passengers were equipped with flotation coats (none had the crotch straps fastened), and a life raft was also available. The raft, however, was stored in the left chin bubble and was lost on impact, as was the Emergency Location Transmitter (ELT).

The occupants egressed in the following manner; the left front passenger was ejected at impact; the right front pilot escaped through a fuselage split; and the two rear seated passengers exited through the right rear door. Several of the passengers clung to the right rotorcraft float that remained inflated until rescue. The occupants remained in the water approximately one hour.

8.3.6 Discussion. This case also demonstrates the shallow flight path run-in scenario but differs from case study two in that this was an unexpected water impact and the post-impact environment was dark and extremely cold. It is important to point out that the death and the serious injuries in this case were caused by exposure and not by impact conditions. It is strongly suspected that the ejected occupant was unrestrained. The severity and types of injuries suggest that the accelerative forces were within the limits of human tolerance. No hydrodynamic effects on the occupants were reported yet the damage to the cabin front suggests that the aircraft interior may have been exposed to a water stream of significant energy.

The flotation coats were not properly used. The report noted that failure to fasten the crotch strap caused the coat to pull up around the wearer's chest. This improper usage caused flotation difficulty for the occupant who became a fatality. Another notable feature of this case was the loss of the life raft and ELT due to their location in the glass chin bubble, which was blown out upon impact.

8.4 CASE STUDY 4

8.4.1 Introduction. This case study describes an accident involving an aircraft from weight class B impacting onto a salt water surface. This accident occurred in daylight with Visual Meteorological Conditions (VMC) conditions prevailing. The wind speed was recorded at 25 kts., gusting to 35 kts., and air temperature was recorded as unknown. The impact surface was recorded as rough with wave heights of twelve feet (sea state five).

Because of the impact parameters, this accident is included in impact scenario three (predominantly longitudinal, steep flight path angle). The post-impact behavior of the rotorcraft in this accident falls within the definition of post-impact scenario two (immediate overturn) because it became submerged immediately. In this accident, there were six people on board: four received fatal injuries and two received serious injuries.

8.4.2 Accident Characteristics. Upon taking off from an oil platform the helicopter suffered a mechanical failure and began spinning to the left. The aircraft was described as hitting the water 183 ft. below the helideck in a left spin, nose and left side low

attitude, with a very high vertical sink rate. A witness stated that the aircraft spun at least three to four times during its descent. Another noted that the tail rotor was not rotating during the descent.

The impact occurred in water with twelve foot waves. Skid-mounted floats were available but separated on impact; a witness thought one may have inflated.

8.4.3 Impact Conditions. The accident was reconstructed using the methodology presented in Appendix C. The impact conditions developed during the reconstruction are given below:

- Velocity Vectors:

Vertical	13 ft/s
Longitudinal	54 ft/s
Lateral	13 ft/s

- Flight Path Angle: 75°

- Attitude:

Roll	– 15° (left)
Pitch	– 60° (nose down)
Yaw	– 5° (left)

8.4.4 Damage. Impact damage to the aircraft was reported as follows:

- Separation of the cockpit/cabin roof and side structure down to the level of the floor.

- The bottom of the aircraft exhibited damage consistent with a high descent rate water impact.

- The two forward seats were substantially damaged but remained partially attached to the floor. structure.

- The left bench seat separated from its attachment.

- Both engines displaced during impact but remained in their mounts.

The skid-mounted floats separated at impact; a witness thought one may have been inflated at impact.

8.4.5 Injury and post-impact Survivability. There were six occupants on board; four suffered fatal injuries and two suffered serious injuries. Of the four fatalities only one died from impact injuries. The injuries and the post-impact survivability aspects for each occupant are discussed below.

- Pilot - right front. This occupant was restrained by a lapbelt and shoulder harness. The front right occupant died from drowning but suffered multiple impact injuries. These injuries were reported as facial lacerations, an abrasion in the pelvic/hip region, a fracture in the chest region, and an ankle dislocation.

- Pax - left front. This occupant was restrained by a lapbelt and shoulder harness. This passenger died as a result of impact injuries which were reported as: fracture of a rib; lacerations of the scalp, right hand, and knee; and transection of the aorta.

- Pax - left middle. The restraint used by this occupant was a lapbelt only. This occupant was not injured by impact. The cause of death was attributed to drowning.

- Pax - right middle. This occupant was restrained by a lapbelt only and was a fatality. The physical evidence of the occupant in the middle right seat was uninspectable due to marine activity.

- Pax - left rear. This occupant was restrained by lapbelt only. This occupant sustained serious impact injuries that were reported as: a compound fracture of the lower left leg, a fracture of the right arm, and a spinal fracture in the lumbar region.

- Pax - right rear. This occupant was restrained by a lapbelt only. This occupant received serious impact injuries that were reported as: a fractured and abraded lower left leg, a fractured right foot, a fractured left elbow, a dislocated upper left elbow, and a facial fracture.

Paths of egress were not noted for any of the occupants. The passengers were equipped with life vests and the two survivors used them until picked up by a work boat approximately five minutes later. One vest appeared to witnesses to be partially torn off the wearer. The two survivors egressed by releasing their two point restraints and exiting just prior to the aircraft sinking.

8.4.6 Discussion. This accident demonstrates survivability aspects for the third water impact scenario; a high longitudinal velocity, steep flight path angle, and steep nose down pitch. This accident was classified as partially survivable because parts of the cabin satisfied the definition of survivability. The narrative description of the impact damage suggests that the occupiable volume was opened and exposed to the water.

Unfortunately, photographs of the fuselage wreckage were not available to visually verify the damage to the occupiable volume. The injury levels of the rear passengers suggest that the accelerations that they experienced were at the upper limits of human tolerance. The effect of the left bench seat separation on injury is unknown, however, and may have also caused injury. One passenger, the left middle occupant, was not injured from the impact.

It is notable that post-impact factors contributed to three of the four fatalities in this case. The helicopter in this case was equipped with skid mounted floats which separated at impact. However, the structural damage to the airframe and the impact conditions may have negated the effect of the aircraft flotation devices even had they survived impact. The psychological shock of the impact and the physical impact injuries may have contributed to the drownings in this water impact.

8.5 CASE STUDY 5

8.5.1 Introduction. This case study describes an accident involving an aircraft from weight class B impacting onto a salt water surface. This accident occurred in daylight with Visual Meteorological Conditions (VMC) prevailing. The wind speed was recorded at 8 kts. and air temperature at 53° F. The impact surface was recorded as calm with a water temperature recorded as 40° F and an average estimated wave height of one half feet (sea state two).

Because its flight path angle exceeded 20 degrees, this accident could not be included in impact scenario two (predominantly longitudinal, shallow flight path angle). The post-impact behavior of the rotorcraft in this accident falls within the definition of post-impact scenario two (immediate overturn). In this event, there were five people on board: one received fatal injuries and four received minor injuries.

8.5.2 Accident Characteristics. While making a final turn for a landing, the aircraft lost main rotor RPM at an altitude of 1000 ft. The low rotor warning horn came on and the pilot initiated an autorotation. At one point, the pilot stated, the RPM decreased through 85 percent. The surviving occupants stated that the warning stayed on throughout the descent. The pilot dropped the collective but did not recover the rotor RPM. As a result, the aircraft landed in the water at a high vertical rate.

Floats were mounted on the skids and these were activated prior to water contact at an altitude of 300 ft. When the rotorcraft struck the surface it became inverted and the floats separated from the fuselage. The rear crosstube became separated as well. The aircraft sank in about 20 seconds, according to the pilot. The surviving passengers clung to the separated but still inflated floats until rescue.

8.5.3 Impact Conditions. The accident was reconstructed using the methodology presented in Appendix C. The impact conditions developed during the reconstruction are given below:

- Velocity Vectors:

Vertical	20 ft/s
Longitudinal	35 ft/s
Lateral	1 ft/s

- Flight Path Angle: 27°

- Attitude:

Roll	0 - 5° (right)
Pitch	5 - 10° (nose up)
Yaw	0°

8.5.4 Damage. The impact damage to the aircraft was as follows;

- The tail rotor and vertical fin were separated from the tail boom just aft of the horizontal stabilizer (figure 8.8).

- One rotor blade had the outer two thirds of its length broken off (figure 8.8).

- The right rear side of the fuselage aft of the right passenger door showed some crushing (figure 8.8).

- The outboard corner of the right rear bench seat exhibited some crushing downward (figure 8.9).

- The pilot's seat showed downward crushing of 1-2 inches

- The rear crosstube separated from the aircraft (figure 8.10).

- The left front door post buckled (figure 8.11).

The floats were inflated at impact and then separated from the aircraft (figure 8.8).

8.5.5 Injury and post-impact Survivability. Five occupants were on board. The injuries and the post-impact survivability aspects for each occupant are discussed below.

Figure 8.8 Case Study 5, Right View of Salvaged Aircraft

Figure 8.9 Case Study 5, Right View of Rear Cabin Seats

Figure 8.10 Case Study 5, Right View of Aircraft Belly

Figure 8.11 Case Study 5, Left View of Aircraft

- Pilot - right front. This occupant was reported as receiving minor abrasions. The restraint used was a lapbelt only. Egress was reported for this occupant to have been through the broken front windshield.

- Pax - left front. Minor lacerations were reported as injuries for this passenger. This occupant used a lapbelt only. The path of egress noted for this occupant was through the broken front windshield.

- Pax - left rear. This occupant received contusions to the pelvis-hip area and the knee. The restraint used was a lapbelt only. This passenger later became a fatality due to egress difficulty.

- Pax —center rear. This occupant suffered minor lacerations and used a lapbelt only restraint. The right rear door was reported as the path of egress for this occupant.

- Pax - right rear. This occupant was reported as having received minor abrasions and used a lapbelt only restraint. Egress for this occupant was also reported to have been through the right rear door.

Life vests were available but were not used by any of the occupants. The middle rear passenger stated that he was unable to release his seatbelt during egress yet still managed to slip out and escape. The left rear passenger remained strapped in his seat, went down with the helicopter, and drowned. At one point the pilot was attempting to pull this passenger more than head-level above the water surface but noted that the passenger appeared to be caught on something. The survivors remained in the water for about 10 minutes until rescue.

8.5.6 Discussion. This accident demonstrates that rapid sinking of the aircraft can eliminate the opportunity to safely egress, even when the occupants survive the impact conditions with only minor injuries. This rotorcraft was equipped with floats that properly inflated prior to impact. Witnesses described the aircraft as breaking up upon hitting the water and this factor appears to have caused the floats to separate and the aircraft to immediately overturn. The occupant injuries were reported as abrasions, lacerations, and contusions. There was no note of injuries due to vertical impact loads. However, the impact damage to the fuselage is characteristic of that caused by significant vertical impact loads. The inflated floats may have absorbed some impact energy and thereby helped to lessen the loads transmitted to the occupants.

8.6 CASE STUDY 6

8.6.1 Introduction. This case study describes an accident involving an aircraft from weight class C impacting onto a salt water surface. This accident occurred in daylight with Visual Meteorological Conditions (VMC) prevailing. The wind speed was recorded

at 17 kts. and air temperature at 63° F. The impact surface was recorded as having wave heights of between two and three feet (sea state three).

Because of the impact kinematics, this accident satisfies the definition of impact scenario one (predominantly vertical, flat impact). The post-impact behavior of the rotorcraft in this accident falls within the definition of post-impact scenario two (delayed overturn). In this accident, there were two people on board: both received serious injuries.

8.6.2 Accident Characteristics. This accident occurred as the rotorcraft was making an overwater final approach at an altitude of 500 ft. The pilot experienced simultaneously a severe airframe vibration, a loud bang, and a yaw of the aircraft to the right. This was later confirmed to be caused by separation of the tail rotor gearbox from the aircraft. The pilot nosed the aircraft over in an attempt to streamline and correct the yaw, however, the yaw continued until impact. The pilot pulled full collective immediately prior to impact. Contact with the surface caused the rotor blades to flex and strike the tail boom and right rear engine cowling.

The skid mounted floats deployed automatically upon impact but several became separated. The occupied area remained upright and afloat for approximately 15 minutes after touchdown. Then, after slowly sinking, the aircraft became inverted.

8.6.3 Impact Conditions. The accident was reconstructed using the methodology presented in Appendix C. The impact conditions developed during the reconstruction are given below:

- Velocity Vectors:

Vertical	30 ft/s
Longitudinal	0 ft/s
Lateral	25 ft/s

- Flight Path Angle: 65°

- Attitude:

Roll	0°
Pitch	10 - 15° (nose down)
Yaw	90° (right)

8.6.4 Damage. Impact damage to the helicopter consisted of the following:

- Ruptured fuel tank.

- 18-inch cabin roof deformation (downward collapse).

- 6-inch floor deformation (upward collapse).

- Buckling, distortion, and collapse of the occupants' seats.

Several of the skid mounted floats separated at impact.

8.6.5 Injury and post-impact Survivability. There were two occupants on board and both received serious injuries. Both occupants were wearing four-point restraints and were in energy absorbing seats which stroked a full 8 inches before bottoming. The injuries and the post-impact survivability aspects for each occupant are discussed below.

- Pilot - front right. This occupant suffered serious injuries which were reported as a spinal dislocation and fracture in the thoracic spine region and a right facial fracture.

- Pax - front left. This occupant suffered serious injuries which were reported as a left facial laceration and fracture and a thoracic spinal fracture.

The left cockpit door could not be opened. Therefore, both occupants exited through the right cockpit door. Both used their inflatable vests and a life raft until they were rescued about 30 minutes later.

8.6.6 Discussion. Impact scenario one (primarily vertical, flat impact) is characterized by this case. The vertical loads from the impact caused serious back injury but the loads did not exceed human tolerance. Also, the occupiable volume deformation was not noted to have impinged on the occupants nor to have caused injury. Therefore, this accident satisfies the definition of survivable. The significant collapse of the fuselage was reported for the left front cabin area and may have prevented the left cockpit exit from operating.

A notable aspect is that the occupied area remained afloat long enough to allow egress of two seriously injured occupants, despite two to three feet waves and incomplete float inflation. The relatively flat curvature of the fuselage bottom may have provided increased water stability for this aircraft.

9. CONCLUSIONS

1. Impact Conditions:

   a. Three survivable water impact scenarios can be defined for rotorcraft:

(1) Primarily vertical impact, steep flight path angle.
(2) Primarily longitudinal impact, shallow flight path angle.
(3) Primarily longitudinal impact, steep flight path angle.

b. Two survivable post water impact scenarios can be defined for rotorcraft:

(1) Immediate overturn.
(2) Delayed overturn.

c. The survivable velocity percentiles in the vertical and lateral directions in the water impact environment are comparable to those found for all impact terrain types.

d. The survivable velocity percentile in the longitudinal direction in the water impact environment is higher than that found for all impact terrain types. The discrepancy may be attributed to longer stopping distances in some of the primarily longitudinal water impacts. Also, the distinct characteristics of the water impact terrain may cause different levels of survivability than found for land impacts.

e. Primarily longitudinal impacts with steep flight path angles were found to be severe but survivable in the water impact environment.

2. Occupant Survivability Hazards:

a. The two main impact hazards to occupant survivability were flailing and excessive decelerative loads.

b. The two main post-impact hazards to occupant survivability were drowning and exposure. Drowning was the most significant hazard, in terms of severity, found for the entire program.

c. Post-crash fire was not found to be a hazard in this study. Although spilled fuel was noted in several cases, there were no recorded occurrences of fire.

3. Aircraft and Personal Flotation Equipment:

a. Aircraft flotation equipment performance was generally found to be inadequate in keeping the rotorcraft upright and afloat, in both ditchings and water impacts. Several cases of successful upright flotation were noted, however. A significant number of the drowning occurrences were noted to occur in cases of immediate aircraft overturn.

b. Aircraft float inflation prior to impact seemed preferred for controlled ditchings. In water impacts, however, aircraft floats inflated prior to impact are more likely to be torn from the aircraft or damaged by the generally more severe impact conditions. In these instances, an immersion sensor seems to be a preferred method of activating aircraft flotation.

c. Personal flotation equipment performance was generally found to be adequate, when utilized by the occupants, in aiding survivability. Several malfunctioning inflatable vests were noted, however. Disuse and malfunctions of personal flotation equipment were both found to contribute to drowning. Life rafts were generally not utilized by occupants in this study.

d. Inadequate awareness of egress procedures, such as restraint release and exit locations, can negatively affect post-impact survivability.

e. Unsatisfactory performance of Emergency Location Transmitters (ELT's), under TSO-C91a, was observed.

10. REFERENCES

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11. GLOSSARY

The following definitions are presented for terms used in this report.

Attitude - Angles describing the orientation of the aircraft relative to the mutually perpendicular aircraft axes. See figure 11.1.

Ditching - An emergency landing on the water, deliberately executed, with the intent of abandoning the rotorcraft as soon as practical. The rotorcraft is assumed to be intact prior to water entry with all controls and essential systems, except engines, functioning properly (reference 10).

Flotation Devices - Inflatable bladders which are mounted either on the skids or lower fuselage of a helicopter. The primary purpose of these flotation devices is to keep the rotorcraft afloat and upright in a ditching situation to allow time for the occupants to safely egress.

Human Tolerance - A measure of the effect of impact forces on the human body, especially the degree of injury associated with those forces. The ability of the human body to sustain impact forces without serious or fatal injury is dependent on many factors, including the orientation of the force relative to the occupant, the type of restraint worn by the occupant, and the physical condition of the occupant. A body of test data is available documenting the effects of impact forces on the human body. Volume II of the U.S. Army Aircraft Crash Survival Design Guide (reference 2) contains a valuable discussion of this subject.

95th Percentile Velocity - A statistical value indicating the velocity associated with the major or principal impact. Up to [illegible] percent of the survivable mishaps are attributable to this velocity (referenc[illegible]

Nonsurvivable Accident - No portion of the cockpit or cabin met the definition of survivable.

Partially Survivable Accident - Some portion of the cockpit or cabin met the definition of survivable (reference 6).

Principal Impact - The impact that occurs when the majority of the decelerative forces were experienced and the most damage was sustained by the fuselage. The principal impact might not have been the initial impact (reference 6).

Significant Survivable Accident - The accident was judged to be either survivable or partially survivable and one or more occupants received impact injuries.

Survivable Accident - The acceleration environment was within the limits of human tolerance, and a sufficient occupiable volume remained for properly restrained (lapbelt and shoulder harness) occupants, with the effects of fire not considered (reference 6).

Velocity Components - Velocity vectors oriented along the mutually perpendicular longitudinal, vertical, and lateral axes of the aircraft. See figure 11.1.

Water Impact - Any impact with water, in which the pilot may have had varying degrees of mechanical control of the aircraft.

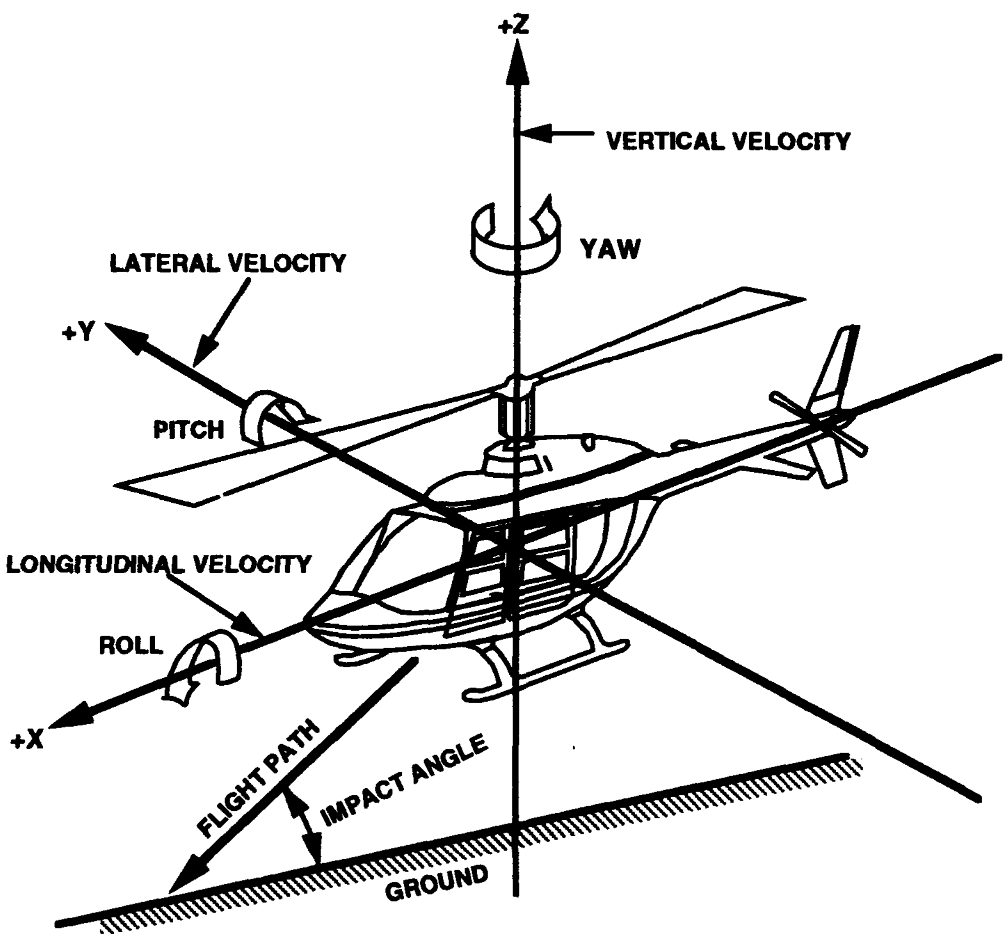

Figure 11.1 Helicopter Attitude and Velocity Component Definitions

APPENDIX A - ACCIDENT DATA SEARCH SOURCES AND RESULTS

The two major sources of water impact accident/incident reports for this investigation were National Transportation Safety Board (NTSB) and the U.S. Army Safety Center. Table A-1 lists the date and location of accidents/incidents from different data search efforts. The original target period for the investigation was 1982 to 1987, but in order to obtain more accident data, the period was expanded to 1982 to 1989. The data search was performed on the NTSB data system and the FAA Accident/Incident Data System (AIDS). Four different searches on AIDS were performed: one in Oklahoma City, two at FAA Headquarters, and one at the FAA Technical Center. Search results varied, due to the different key words used in performing the searches.

Another data search effort was attempted through the International Civil Aircraft Organization (ICAO). Table A-2 lists the number of water impact accidents/incidents from fourteen countries during the years 1982 to 1989.

Table A.1 List of Accident Data Identified from NTSB and FAA Sources

Source of Report - Rotorcraft Ditching 5/28/91								
NTSB	FAA Accident/Incident Data System **						Accident	Accident
	OKC	HQ 1	TC	HQ 2	accident	incident	Date	Location
1	1				A		1/27/82	LAGUNITAS CA
1					A		2/4/82	SHIP SHOAL GM
1					A		4/21/82	CROOM FL
1					B		4/22/82	INTRACOASTAL CITY LA
	1				A		4/23/82	GALVESTON TX
1					A		4/29/82	NEW YORK CITY NY
1	1				A		10/5/82	SANDWICH IL
1					A		11/8/82	ANITA BAY AK
1					B		11/22/82	BUCCANEER OIL FIELD GM
1	1				A		12/3/82	WEST CAMERON BLK 180
1					A		2/21/83	BOCA RATON FL
1	1				A		6/10/83	GOLETA CA
1	1				A		9/14/83	CHICAGO IL
1					B		9/15/83	CAPE YAKATAGA
1							4/4/84	WEST CAMERON 540 GM *
1							5/1/84	GULF OF MEXICO *
1					B		6/8/84	SOUTH PELTO GM
1					B		7/21/84	HIGH ISL BLK 298 GM
1					X		7/28/84	POINT LOMA CA
1					A		8/13/84	GROSS ILE MI
	1				A		10/12/84	HUEYTOWN AL
1					B		11/12/84	E CAMERON BLK 2 GM
			1		A		1/3/85	SALT LAKE CITY UT
1			1		B		1/10/85	KENAI AK
1	1	1	1	1	A		1/21/85	HONOLULU HI
			1		A		2/25/85	SANTA BARBARA CA
			1		A		4/20/85	GULF OF MEXICO FL
1							4/26/85	NEW YORK CITY NY *
	1	1				C	5/13/85	GULF OF MEXICO TX
1	1	1	1		B		6/15/85	LAHAINA HI
1	1	1	1	1	A		6/16/85	MANHATTAN BEACH CA
			1		A		7/7/85	SUMMIT LAKE AK
	1				B		7/16/85	HOONAH AK
1	1	1	1		B		7/21/85	SOUTH MARSH BLK 57 GM
			1		A		8/25/85	ELIZABETHTOWN KY
1					A		9/17/85	PACIFIC OCEAN PO
1					B		9/29/85	NORTH PADRE 967 GM
1	1	1	1		A		10/5/85	ISLAMORADA FL
1	1	1	1		A		10/21/85	MARCO ISLAND FL
			1		A		1/9/86	GULF OF MEXICO LA
			1		A		3/21/86	AFTON CA
	1	1	1	1	A		4/18/86	RIDGEFIELD PARK NJ
1	1	1	1		A		4/27/86	RIDGEFIELD PARK NJ
	1				A		5/6/86	AGANA GQ
1	1	1	1		A		5/23/86	NOMANS LAND ISLAND
1	1				B		6/2/86	PETERSON AL
1			1		A		7/4/86	ISLAMORADA FL
1	1		1		A		7/6/86	FALL RIVER MA
1					B		7/17/86	STATEN ISLAND NY
1	1		1		B		8/30/86	GRAND ISLE GM
1					B		9/20/86	ATLANTIC OCEAN AO
1	1				B		10/16/86	LOMPOC CA
1			1		A		10/22/86	MANHATTAN NY
			1			C	11/1/86	CORPUS CHRISTI TX
1	1		1		A		12/11/86	NEWPORT RI
1	1		1		B		2/5/87	MATAGORDA 665 GM
	1					C	2/5/87	VENICE LA
1	1				A		2/8/87	HONOLULU HI
1	1	1			A		2/13/87	BUFORD GA
	1					G	2/18/87	GULF OF MEXICO LA
			1		A		3/22/87	HOMOSASSA FL
	1					C	3/23/87	GALVESTON TX
1	1	1		1	B		3/29/87	KAILUA KONA HI
1					B		4/15/87	LAUPAHOEHOE HI
	1					C	4/18/87	GALVESTON TX
1					A		4/21/87	BAY MINETTE AL

Table A.1 List of Accident Data Identified from NTSB and FAA Sources — (Continued)

Source of Report - Rotorcraft Ditching 5/28/91								
NTSB	FAA Accident/Incident Data System **						Accident	Accident
	OKC	HQ 1	TC	HQ 2	accident	incident	Date	Location
1	1				A		4/29/87	TAMUNING GQ
1	1	1	1		A		5/3/87	PANAMA CITY BCH FL
	1					C	6/1/87	FOURCHON LA
	1					C	6/5/87	AMELIA LA
	1				B		6/25/87	NEW YORK NY
	1	1	1	1		C	6/29/87	PATTERSON LA
1	1				B		7/4/87	VENICE LA
1	1		1		A		7/23/87	HUNTSVILLE AL
1	1					C	7/28/87	NANTUCKET MA
	1				A		8/5/87	BURRVILLE RI
1	1		1		A		8/19/87	SHIP SHOAL 214C GM
1	1		1		B		9/16/87	GULF OF MEXICO OF
	1					G	10/15/87	HANA HI
1	1	1			A		10/24/87	KEY COLONY BCH. FL
1	1		1		A		12/7/87	GALVESTON TX
	1					C	3/10/88	VENICE LA
	1					C	4/25/88	GULF OF MEXICO TX
1	1				A		5/1/88	LONG ISLAND CITY NY
	1					C	5/2/88	GALVESTON TX
	1					C	5/12/88	FREEPORT TX
	1		1			G	5/29/88	HAMPSTEAD NH
1	1	1			B		5/29/88	HONOLULU HI
			1			G	6/18/88	W BOYLSTON MA
1	1	1	1	1	A		6/25/88	NEWBURYPORT MA
1	1		1		A		7/13/88	MARINA DEL RAY CA
1	1	1		1	B		7/14/88	GULF OF MEXICO
	1				A		7/18/88	CLEWISTON FL
1	1		1		A		8/5/88	OAKLAND ME
	1					G	8/5/88	GRAND ISLE LA
	1	1	1	1	A		8/6/88	BOCA RATON FL
	1					C	8/18/88	GULF OF MEXICO MS
	1					G	8/25/88	NORTH MYRTLE BEACH SC
	1		1		A		9/1/88	GULF OF MEXICO TX
1	1			1	B		11/4/88	WEST CAMERON LA
1	1	1			A		11/10/88	ST THOMAS VI
	1					C	11/16/88	LEESVILLE LA
1	1			1	B		11/17/88	GULF OF MEXICO TX
	1				A		11/23/88	CHALMETTE LA
			1		A		12/12/88	OKEELANTA FL
	1				B		12/15/88	SOUTH MARSH 113 LA
	1					C	12/18/88	VENICE LA
	1				A		12/18/88	LINWOOD KS
1			1		A		12/20/88	OAKLAND CA
	1				A		12/23/88	CRYSTAL RIVER FL
1	1				A		1/3/89	SOUTH TIMBALIER LA
1	1	1		1	A		3/20/89	SAIPAN TQ
	1					C	4/28/89	GULF OF MEXICO TX
	1					C	6/9/89	GULF OF MEXICO LA
	1					G	6/13/89	MT WILSON CA
	1			1		C	6/30/89	FULTON TX
	1					C	7/2/89	CAMERON LA
	1					C	7/4/89	VALDEZ AK
	1					C	7/15/89	GULF OF MEXICO LA
	1					G	7/29/89	GUILFORD NH
			1		A		7/30/89	BRINNON WA
1	1			1	A		8/2/89	PHILADELPHIA PA
1	1			1	A		8/16/89	MILBRIDGE ME
	1					C	4/25/88	GULF OF MEXICO TX
1	1				A		9/6/89	MURIETTA CA
1			1		A		9/15/89	LOUISVILLE GA
	1					C	11/24/89	GULF OF MEXICO LA
	1					C	12/24/89	GULF OF MEXICO LA
73	89	21	42	14	93	33	128	

** A = General Aviation Accident
B = Air Carrier Accident
C = Air Carrier Incident
D = General Aviation Incident

Table A.2 Summary of Rotorcraft Water-Impact Accidents (1982-1989) Reported by ICAO

Country	No. of Accidents	Subtotal
United States *	14	14
Australia	1	25
Brazil	2	
Canada	3	
Denmark	1	
Fiji	1	
France	1	
Germany	1	
Iceland	1	
Japan	1	
Sierra Leone	1	
Thailand	1	
United Arab Emirate	1	
United Kingdom	10	
Total	**39**	

** Already obtained from NTSB*

APPENDIX B - ACCIDENT RECONSTRUCTION FORM DEFINITIONS AND CODES

INTRODUCTION

This appendix describes the format of the accident reconstruction forms used to summarize the raw accident data into a format suitable for analysis. For each of the three main classifications, or sequences, the appendix describes type of information contained in that sequence, then presents the data definitions used on the accident reconstruction forms. Examples of the accident reconstruction forms appear at the end of this appendix.

Sequence 1, General Accident Information

Introduction

Sequence 1 of the Accident Reconstruction Form recorded information specific to each accident in the study. Information was broken into nine logical areas as follows:

1. Accident identification information
2. Aircraft identification information
3. Accident type
4. Accident severity summary
5. Impact velocities and attitude
6. Environmental conditions
7. Accident sequence of events
8. Aircraft damage summary
9. Aircraft flotation equipment damage.

1. Accident Identification Information

Case Number - The number assigned to the accident in question.

Source - Accident report source of data (e.g. NTSB).

Location - The location of the accident. Usually the city and state in which the accident occurred, the closest city and state to the accident for cases offshore, or some other identifier (e.g. oil rig).

Date - Date of occurrence, MM/DD/YY.

Time - Local time of day when accident occurred, HH:MM, on 24 hour clock.

2. Aircraft Identification Information

Registration Number - The official FAA licensed registration number or tail number assigned to the aircraft.

Manufacturer - The manufacturer of the aircraft.

Model - The manufacturer's aircraft model number or U.S. Army designation.

Weight - The aircraft design gross weight (DGW) in pounds.

Seats - The total number of occupant seats on the aircraft as configured at the time of the accident.

3. Accident Type

Accident Type - The type of event as defined by the following 42 codes derived from the NTSB. There are five fields allocated for describing the accident type: A,B,C,D,E. The 42 codes are listed below:

Code	Type of Accident
1	Abrupt maneuver
2	Altitude deviation, uncontrolled
3	Airframe/component/system fail./malfunction
4	Ditching
5	Dragged wing, rotor, pod, or float
6	Fire/explosion
7	Fire
8	Forced landing
9	Gear collapsed
10	Main gear collapsed
11	Nose gear collapsed
12	Complete gear collapsed
13	Gear not extended
14	Hard landing
15	In flight collision with object
16	In flight collision with terrain
17	In flight encounter with weather
18	Loss of control - in flight
19	Loss of control - on ground
20	Midair collision
21	Near collision between aircraft
22	Nose down
23	Nose over
24	On ground collision with object
25	On ground collision with terrain
26	On ground encounter with weather
27	Overrun
28	Loss of power
29	Loss of power (total) - mech fail/malfunction
30	Loss of power (partial)- mech fail/malfunction
31	Loss of power (total) - non-mechanical
32	Loss of power (partial) - non-mechanical
33	Propeller blast or jet exhaust/suction
34	Propeller/rotor contact
35	Roll over
36	Undershoot
37	Undetermined
38	Vortex turbulence encountered
39	Missing aircraft
40	Miscellaneous/other

41	Not reported
42	Other

4. Accident Severity Summary (Injury Summary, Aircraft Damage)

Damage - Indicates the extent of the damage to the aircraft. The codes are:

Code	Damage
D	- Destroyed
S	- Substantial
M	- Minor
N	- None
U	- Unknown

Recovered - Was the aircraft recovered?

Code	Recovered?
Y	- Yes
N	- No
U	- Unknown

Terrain - The type of terrain encountered upon impact. The following table indicates the eighteen possibilities. For this study the terrain was water (Code K) in all cases.

Code	Terrain
A	- Mountainous
B	- Hilly
C	- Rolling
D	- Level, flat
E	- Frozen
F	- Rocky
G	- Sandy
H	- Dense with trees
I	- City Area
J	- Plowed
K	- Water
L	- Sloped
M	- Snow
P	- Paved
R	- Off-shore Rig
S	- Soft
Y	- Other
Z	- Unknown

Fire - Indicates the presence of a fire, and if so, was it a factor?

N - No, fire was not a factor
P - Yes, fire was a factor, Postcrash fire
I - Yes, fire was a factor, Inflight fire
G - Yes, fire was a factor, Ground fire, not associated with the accident
U - Unknown

Survivable - Indicates the degree of occupant survivability in the accident.

The codes indicating levels of survivability are:

S - Survivable
P - Partially Survivable
N - Nonsurvivable
U - Unknown

Survivable - the acceleration environment was within the limits of human tolerance, and a sufficient occupiable volume remained for properly restrained (lapbelt and shoulder harness) occupants, with the effects of fire not considered.

Partially Survivable - Some portion of the cockpit or cabin met the definition of survivable.

Nonsurvivable - No portion of the cabin met the definition of survivable.

5. Impact Velocities and Attitudes

Velocity vectors and impact attitudes are calculated during accident reconstruction. These values are recorded for both the initial and principal impact, if appropriate.

Principal and Initial Impact:

Initial Impact is defined as the aircraft's first contact with the impact surface. Principal Impact is defined as the impact associated with causing the majority of the damage to the aircraft and injuries to the occupants. In most cases, the initial impact and principal impact coincide.

Velocity Vectors:

Velocity vectors are calculated in the aircraft coordinate system. Longitudinal, Vertical, and Lateral Velocities which are oriented along the aircraft's mutually perpendicular coordinates axes, are recorded in ft/s. The resultant of these velocity components is also calculated.

Impact Attitudes:

Roll - roll is the aircraft's degree of rotation measured from level about its' longitudinal X-axis. It ranges from (+)90 degrees to (-)90 degrees. Right roll is designated as positive and left roll is negative.

Pitch - pitch is the aircraft's degree of rotation measured from level about its' lateral Y-axis. It is measured as the angle between the aircraft's longitudinal X-axis and the horizontal.

Pitch can range from (+)90 degrees to (-)90 degrees. Nose-up is designated as positive and nose-down is negative.

Yaw - yaw is the aircraft's degree of rotation of its nose about its vertical Z-axis. It ranges from (+)180 degrees to (–)180 degrees and is measured from the flight path. Right yaw is designated as positive and left yaw is negative.

6. Environmental Conditions

Type of Water - type of water encountered upon impact.

F	- Fresh
S	- Salt
O	- Other
U	- Unknown

Sea State - Classification of water surface by wave height. Enter numerical wave height(ft). (–1 = unknown)

Wind - average wind speed in knots is indicated, wind direction in clockwise degrees from North (range is 0 to 360 degrees). If available, the speed of wind gusts in knots is recorded.

Weather - indicates basic prevailing weather conditions for aircraft operations:

V	- Visual Meteorological Conditions (VMC)
I	- Instrument Meteorological Conditions (IMC)
U	- Unknown

Water Temperature - indicated in degrees Fahrenheit.

Air Temperature - indicated in degrees Fahrenheit.

7. Accident Sequence of Events

Describes in detail the sequence of events leading up to and including the accident.

8. Aircraft Damage Summary

Describes in detail the damage to the aircraft in the accident. Overall structural damage as well as damage to specific aircraft subsystems is indicated.

9. Aircraft Flotation Equipment Damage

Describes the extent of damage to the aircraft's flotation equipment in the accident.

Water Impact Reconstruction Form
Data Definitions and Codes

Sequence 2, Injuries to Occupants

Introduction

Sequence 2 of the Accident Reconstruction form recorded information on the injuries sustained by occupants during the accident. The purpose was to assess the impact and post-impact survivability aspects for each occupant. Information was broken into 5 logical areas as follows:

1. Occupant identification/location information
2. Injury information
3. Occupant restraint information
4. Personal flotation/exposure information
5. Comments

1. Occupant identification/location information

Occupant - The number assigned is used to identify the occupant throughout the reconstruction form. Also, the role of the occupant is listed as pilot or passenger and the name is given if available.

Position in A/C - For categorization and analysis purposes, the location of each occupant is assigned a seating position code corresponding to the following table. The table depicts nine (9) seating positions from a top view of the aircraft.

Seating Position Codes

	Port	Center	Starboard
Front	FP	FC	FS
Middle	MP	MC	MS
Aft	AP	AC	AS

Codes are as follows:

FP - Front, Port
FC - Front, Center
FS - Front, Starboard
MP - Middle, Port
MC - Middle, Center
MS - Middle, Starboard
AP - Aft, Port
AC - Aft, Center
AS - Aft, Starboard
OT - Other
UK - Unknown

2. Injury Information

Injury Degree - The overall degree of injury sustained by the occupant in the accident is indicated in the following codes:

Code	Overall Injury Degree
F	- Fatal
S	- Serious
M	- Minor
N	- None
U	- Unknown

Injury Type - The specific type of the particular injury (from NTSB Form 6120.4 Supplement K (1-84), Lesion - C) is listed as:

01 Laceration
02 Contusion
03 Abrasion
04 Fracture
05 Concussion
06 Avulsion
07 Rupture
08 Sprain
09 Dislocation
10 Crush
11 Amputation
12 Burn
13 Fracture and dislocation
14 Severance (Transection)
15 Strain
16 Detachment (Separation)
17 Perforation (Puncture)
18 Suffocation
88 Injured unknown lesion
99 Other

Injury Location - The bodily location of the particular injury (from NTSB Form 6120.4 Supplement K (1-84), Body Region - A) is listed as:

01 Head (Skull, scalp, ears)
02 Face (Forehead, nose, eyes, mouth)
03 Neck (Cervical spine, C1-C7)
04 Shoulder (Clavicle, scapula, joint)
05 Upper limb (Whole arm)
06 Arm (Upper)
07 Elbow
08 Forearm
09 Wrist
10 Hand-fingers
11 Chest (Anterior and posterior ribs)

12 Abdomen (Diaphragm and below)
13 Back (Thoracic spine T1-T12)
14 Back (Lumbar L1-L5)
15 Pelvis-hip
16 Lower limb (Whole leg)
17 Thigh (Femur)
18 Knee
19 Leg (Below knee)
20 Ankle
21 Foot-toes
22 Whole body
88 Injured, unknown region
99 Other

Injury Severity - The general severity of the particular injury (from NTSB Form 6120.4 Supplement K (1-84), Abbreviated Injury Scale - E) is listed as:

00 Not injured
01 Minor injury
02 Moderate Injury
03 Serious Injury (Not life-threatening)
04 Severe Injury (Life-threatening survival probable)
05 Critical injury (Survival uncertain)
06 Maximum (Untreatable - fatal)
07 Injured (Unknown severity)
88 Unknown if injured

Injury Cause - The cause or source of the particular injury (from NTSB Form 6120.4 Supplement K (1-84), Injury Source List - F) is listed as:

01 Windshield
02 Windshield frame
03 Window
04 Window frame
05 Instrument panel
06 Side console
07 Center console
08 Control stick/cyclic stick
09 Collective
10 Control yoke/column
11 Throttle quadrant/levers
12 Rudder pedals
13 Ceiling
14 Sidewall
15 Floor
16 Fuselage framing/structure
17 Table
18 Seat
19 Seatback tray
20 Restraints-seatbelt/tiedown
21 Restraints-shoulder harness
26 Unsecured seat(s)
27 Outside object(s) entering aircraft
28 Galley item(s)
29 Food/beverage item(s)
30 Other interior objects
31 Other exterior objects
32 Evacuation slide/slide raft
33 Escape rope/tape
34 Escape inertia device
35 Ejected from aircraft
36 Propeller/rotor blades
37 Exterior aircraft surface
38 Engine
39 Wheel/tires
40 Ground vehicle
41 Toxic/noxious/irritant fumes
42 Fire/radiant heat
43 Flying glass
44 Door/hatches
45 Acceleration forces
46 Exposure

22 Unsecured item(s) in cockpit
23 Unsecured item(s) in cabin
24 Other occupants
25 Ground/runway
47 Glare shield
48 Eyeglasses
49 Inhalation of water
88 Unknown
99 Other

Water Impact (WI) - This category is indicated with a check if the particular injury was caused by the impact of the aircraft with the water. For example: the occupant strikes his head on the instrument panel due to velocity change at impact.

Post-Impact (PI) - This category is indicated with a check if the particular injury was caused by post-impact conditions. For example: the occupant drowns after ditching.

3. Occupant restraint information

Restraint - The type of restraint worn by the occupant at time of impact is listed as 2-point, 3-point, 4-point, 5-point, none, or unknown. Codes are:

0 - None used, 0
2 - 2-point
3 - 3-point
4 - 4-point
5 - 5-point
U - Unknown

4. Personal flotation/exposure information

Personal Flotation - The type of personal flotation worn by the occupant at time of impact and/or used by the occupant in the post-crash environment is listed as life-vest, inflatable vest, not used, not available, unknown, or not applicable. This last designation is made if the nature of the incident was such that personal flotation was irrelevant (example: non-survivable impact).

Time in Water (TIW) - This is the recorded time, if available, or estimated time, if evidence permits, that the occupant is involved in the ditching environment, from moment of impact to rescue. This is recorded to the nearest five minute interval. Periods of time below a total of five minutes in the ditching environment are recorded to the nearest minute. The value -1 was recorded if the time in the water was unknown.

5. Comments

Comments - These are short phrases used by the accident reconstructionist to elaborate upon the nature or cause of injuries if the codes do not provide sufficient detail or are not applicable due to lack of information in accident data.

Water Impact Reconstruction Form
Data Definitions and Codes

Sequence 3, Post-Impact Survivability

Introduction
Sequence 3 of the Accident Reconstruction form recorded information on post-impact survivability aspects of occupants in the ditching environment. The purpose was to assess the performance of the aircraft's ditching and flotation equipment and how this equipment's performance affected occupant egress and consequently overall survivability. The information was divided into three (3) major areas:

1. Aircraft Flotation Equipment
2. Aircraft Float Effectiveness
3. Occupant Egress

1. Aircraft Flotation Equipment

Aircraft Landing Gear Configuration - Indicates the landing gear type and its status upon impact. For example, retractable wheel gear in the up position upon impact. Options available on the form are circled by the reconstructor if relevant. These include:

Landing Gear Type: Skid, Wheel, Retractable
Landing Gear Status: Up, Down

The landing gear configuration can also be indicated by the following codes:

SK - Skid
WN - Wheel, Non-retractable
WU - Wheel, Retractable, Up
WD - Wheel, Retractable, Down
OT - Other
UN - Unknown

Floats Installed? - Indicates the presence of floats on the aircraft. Codes are:

Y - Yes
N - No
U - Unknown

Float Type - Documents the type of float used on the aircraft: emergency pop-out, ditching floats, etc. For aircraft without floats, "Not Applicable" is indicated on the form.

Location on Aircraft - Documents the location of floats on the aircraft. Codes are:

S - On Skids
F - On Fuselage
O - Other mounting configuration
U - Unknown
X - Not Applicable, X, for no floats on aircraft

Floats Armed? - Indicates if the floats were armed at impact.

- Y - Yes
- N - No
- U - Unknown
- X - Not Applicable, X, for no floats on aircraft

Activated? - Indicates if the floats were activated and if so, how and when they were activated.

How the floats were activated is indicated by the following codes:

- M - Manually Activated
- A - Automatically Activated
- N - Not Activated
- U - Unknown
- X - Not Applicable, X, for no floats on aircraft

When the floats were activated is indicated by the following codes:

- B - Before or Pre-Impact
- P - Post-Impact
- A - At Impact
- U - Unknown
- X - Not Applicable, X, for floats never activated or floats not on aircraft

Did Floats Survive Impact? - Codes are as follows:

- Y - Yes
- N - No
- U - Unknown
- X - Not Applicable, X, for no floats on aircraft

Comments - Indicates additional information about the aircraft flotation equipment which influences post-impact occupant survivability. Examples include the reasons why floats were damaged, uneven float deployment, overall performance of float deployment.

2. Aircraft Float Effectiveness

Aided Occupant Egress? - Indicates in general, if the floats assisted in the occupants' egress of the ditched aircraft.

- Y - Yes
- N - No
- U - Unknown
- X - Not Applicable, X, could not aid egress because there were no floats on aircraft

Aided Survivability? - Indicates in general, if the floats increased the occupants' chances of survival and reduced the risk of injury.

- Y - Yes
- N - No

U - Unknown
X - Not Applicable, X, for no floats on aircraft

Time Aircraft Remained Upright - Indicates the time in minutes, if available, that the aircraft remained upright in the water. This duration was rounded to the nearest 5 minutes for values over 5 minutes, otherwise the time was recorded to the nearest minute.

Cause of Overturning - Indicates the most probable cause of overturning the aircraft. Codes are as follows:

I - Intentional
A - Impact Attitude
W - Weather (rough seas or high winds)
D - Uneven Float Deployment
F - Float Problems other than uneven float deployment.
X - Not Applicable, X, Did Not Overturn
N - Not Equipped with Floats
O - Other
U - Unknown

Time Aircraft Remained Afloat - Indicates how long the aircraft remained afloat for in minutes. This duration was rounded to the nearest 5 minutes for values over 5 minutes, otherwise the time was recorded to the nearest minute. The value -1 was recorded if the time in the water was unknown.

Other - Used for any other information pertinent to aircraft flotation equipment performance.

Comments - Documents any additional information on aircraft flotation effectiveness and its relation to post-impact occupant survivability.

3. Occupant Egress

Occupant - References the same occupant number assigned to each person from Sequence 2.

Exit Used - Documents the exit that the occupant used to egress from the aircraft. For categorization and analysis purposes, the location of each exit an occupant used in exiting the aircraft is assigned a code corresponding to the following table. The table depicts nine (9) exit locations from a top view of the aircraft.

Exit Location Codes

	Port	Center	Starboard
Front	FP	FC	FS
Middle	MP	MC	MS
Aft	AP	AC	AS

Codes are as follows:

FP - Front, Port
FC - Front, Center

FS - Front, Starboard
MP - Middle, Port
MC - Middle, Center
MS - Middle, Starboard
AP - Aft, Port
AC - Aft, Center
AS - Aft, Starboard
OT - Other
NO - None, for no exit used
UK - Unknown

The type of exit used can also be classified by using the following codes:

D - Door
W - Window
H - Overhead Hatch
F - Fuselage Split
U - Unknown
X - Not Applicable, X, no exit used because occupant never exited aircraft

Aircraft —Indicates the flotation status of the aircraft during occupant egress. An "X" was placed in the appropriate column to record the aircraft's flotation status during each occupant's egress. The column headings appear on the form as follows:

FLO - Floating
PSB - Partially Submerged
SIN - Sinking
ROB - Resting On Bottom
UNK - Unknown
OTH - Other

If the aircraft flotation status at egress was unknown, no columns were marked.

Personal Flotation - Indicates whether or not personal flotation was available.

Y - Yes
N - No
U - Unknown

Types - Documents the types of personal flotation available to each occupant. Options include:

Vest, Inflatable
Vest, Non-Inflatable
Seat Cushion
Liferaft
None Available

Used? —Indicates whether or not personal flotation was used.

Y Yes
N No

- U Unknown
- X Not Applicable, X, no personal flotation was used because none was available.

Work? - In general, indicates whether or not personal flotation functioned satisfactorily.

- Y Yes
- N No
- U Unknown
- X Not Applicable, X, for no personal flotation was used and therefore its function was irrelevant. (e.g. for impact fatalities, personal flotation function not applicable.)

How Long? —Indicates how long the personal flotation devices worked properly in minutes. This duration was rounded to the nearest 5 minutes for values over 5 minutes, otherwise the time was recorded to the nearest minute. No entry was made if personal flotation was unavailable, not used, or did not work.

Comments —Documents any additional information on occupant egress and personal flotation and their relation to post-impact occupant survivability.

WATER IMPACT RECONSTRUCTION FORM

CASE NUMBER:		VELOCITY VECTORS				IMPACT ATTITUDE		
LOCATION:		VERTICAL	LONG.	LATERAL	RESULTANT	ROLL	PITCH	YAW
DATE AND TIME:	INITIAL IMPACT							
REG. NUMBER:								
MODEL: DGW:	PRINCIPAL IMPACT							
ACC. REPORT SOURCE:								

A/C RECOVERED:	INJURY SUMMARY	TYPE OF ACCIDENT	ENVIRONMENTAL CONDITIONS
DAMAGE:	FATAL:	A:	TYPE OF WATER:
TERRAIN:	SERIOUS:	B:	SEA STATE:
FIRE:	MINOR:	C:	WIND:
SEATS:	NONE:	D:	WEATHER:
SURVIVABLE:	ON BOARD:	E:	WATER TEMP: AIR TEMP:

SEQUENCE OF EVENTS

DAMAGE TO A/C STRUCTURE

DAMAGE TO A/C FLOTATION EQUIPMENT

SIM 125

REV 11/01/90

WATER IMPACT RECONSTRUCTION FORM

SEQUENCE 2 OF 3
SHEET ___ OF SEQUENCE 2

CASE NO.____ REG. NO.________

INJURIES TO OCCUPANTS

OCCUPANT	POSITION IN A/C	INJURY DEGREE	OCCUPANT SURVIVABILITY							
			RESTRAINT: 2-PT 3-PT 4-PT 5-PT NONE						PERS. FLOTATION:	
			TYPE	LOC.	SEV	CAUSE	WI	PI	T/W	COMMENTS
			RESTRAINT: 2-PT 3-PT 4-PT 5-PT NONE						PERS. FLOTATION:	
			TYPE	LOC.	SEV	CAUSE	WI	PI	T/W	COMMENTS
			RESTRAINT: 2-PT 3-PT 4-PT 5-PT NONE						PERS. FLOTATION:	
			TYPE	LOC.	SEV	CAUSE	WI	PI	T/W	COMMENTS
			RESTRAINT: 2-PT 3-PT 4-PT 5-PT NONE						PERS. FLOTATION:	
			TYPE	LOC.	SEV	CAUSE	WI	PI	T/W	COMMENTS

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REV 11/01/80

WATER IMPACT RECONSTRUCTION FORM

POSTIMPACT SURVIVABILITY

CASE NO. ____ REG. NO. ____

A/C FLOTATION EQUIPMENT

A/C LANDING GEAR CONFIGURATION: SKID WHEEL RETRACT UP DOWN

FLOATS INSTALLED: FLOAT TYPE:

LOCATION ON A/C:

FLOATS ARMED: ACTIVATED: AUTO MANUAL PREIMPACT POSTIMPACT NOT

DID FLOATS SURVIVE IMPACT:

COMMENTS

A/C FLOAT EFFECTIVENESS

AIDED OCCUPANT EGRESS:

AIDED SURVIVABILITY:

TIME A/C REMAINED UPRIGHT: CAUSE OF OVERTURNING:

TIME A/C REMAINED AFLOAT:

OTHER:

COMMENTS

OCCUPANT EGRESS

OCC.	EXIT USED	AIRCRAFT				PRS FLTN	TYPES	USED	WORK	HOW LONG	COMMENTS
		FL	PS	SIN	ROB						

SIM 125

REV 11/01/90

APPENDIX C - SAMPLE CASE TO DEMONSTRATE ACCIDENT RECONSTRUCTION METHODOLOGY

<u>Summary</u>: A large helicopter with two turboshaft engines was used in an on-demand air taxi operation between the coastline and oil rigs in the Pacific Ocean. Before the accident happened, the pilot was trying to land the helicopter on an oil rig located 1 1/3 miles off shore.

The pilot stated that the tail rotor pedals began to vibrate when he reduced power to descend. The vibration worsened with a further reduction of power intended to slow the airspeed. The pilot planned a descent so as to be closer to the water in the event of complete tail rotor failure. The aircraft unexpectedly struck the water before the pilot armed the automatically actuated emergency flotation bags. The sea state was calm with 1-2 feet swells. The wind was 4 knots from the north.

<u>Aircraft Damage</u>: The aircraft was destroyed. There was minor damage to the upper cabin. The main rotor blades, main rotor assembly, tail rotor gear box, and vertical fin pylon separated after impact. There was evidence of contact observed between the main rotor and vertical fin, between the main rotor and the 42 degree drive shaft cover, between the tail rotor and main rotor, and between the tail rotor and vertical fin.

<u>Survival Aspects</u>: The pilot was wearing a lapbelt and dual shoulder harness at the time of impact. The three passengers had lapbelt restraints. The aircraft sank immediately after impact. The pilot escaped through the emergency window on the right side of the aircraft and received no injury. One passenger exited through the door on the left side of the aircraft and was also uninjured. The other two passengers did not exit the aircraft and were assumed drowned.

<u>Accident Kinematics</u>: According to pilot the impact with the water was mild. The passengers stated that it was like a normal landing. The witness on the oil rig platform also stated that it looked like a normal landing. The structural damage was mainly caused by the contact of main rotor blades with tail structures including tail rotor blades, vertical fin, tail rotor drive shaft cover.

Based on the above observations, the aircraft was assumed to have 5 -10° pitch nose up, 0° roll, 0° yaw, and a shallow flight path angle of 10-15° A sink rate of 5 ft/s. was used as an initial assumption because it is a typical value for a normal rotorcraft landing.

Velocity Component Estimates:
Let the pitch angle be 7.5° nose up and the flight path angle be 12.5°. The velocity components in aircraft coordinates can then be calculated as follows:

$$\text{The resultant speed} = \frac{5}{\sin 12.5^\circ}$$

$$\text{Vertical velocity, } V_V = 23.1 \sin(7.5 + 12.5)$$
$$V_V = 23.1 \sin 20^\circ$$
$$V_V = 7.9 \text{ ft/s}$$

$$\text{Longitudinal speed, } V_L = 23.1 \cos 20^\circ = 21.7 \text{ ft/s}$$

Deceleration Pulse Estimates:
A uniform triangular deceleration pulse was used to simulate the vertical impact conditions. There were no reported injuries due to vertical impact loads therefore the pulse was assumed to be 10 g's or less. The stopping time calculated for the vertical velocity of 7.9 ft/s was 0.049 seconds. A 10 g pulse of 0.049 seconds duration is within the limits of human tolerance without injury from whole body acceleration. Also, the main rotor struck the tail rotor and tail structure, which can be expected for this g-pulse. Therefore the vertical velocity estimate was considered reasonable.

$t = 2(V_v)/G(a_g)$
$t = 2(7.9 \text{ ft/s})/10(32.2 \text{ ft/s})$
$t = 0.049 \text{ s}$

A uniform triangular deceleration pulse was also used to simulate the longitudinal impact conditions. A 25 g pulse was assumed for this direction which resulted in a 0.054 second pulse duration for a longitudinal impact velocity of 21.7 ft/s. A pulse of this magnitude and duration is within the limits of human tolerance for properly restrained occupants.

$t = 2(V_v)/G(a_g)$
$t = 2(21.7 \text{ ft/s})/25(32.2 \text{ ft/s})$
$t = 0.054 \text{ s}$

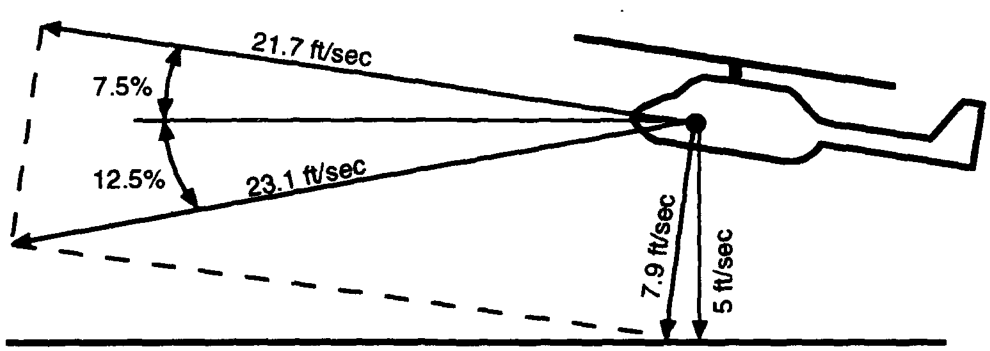


Figure C.1 Impact Attitude and Impact Velocity Components Diagram

APPENDIX D - WATER IMPACT ACCIDENT DATABASE FOR ROTORCRAFT

Database Design and Description of Files

Introduction

This appendix describes the construction of a database used to assist the categorization of the data collected in the accident reconstruction phase. The data was taken from the previously completed Water Impact Accident Reconstruction Forms. The information on the forms was incorporated into the database, however, it was not stored in the same order. Instead of dividing the information into General Accident Information, Injuries to Occupants, and Post-Impact Survivability as the Reconstruction Forms do, the database collected information in three separate but logically related files as described below.

Description of Database Files

Three separate files were created (the '.dbf' file extension denotes database file):

1. ACCIDENT.dbf
2. OCCUPANT.dbf
3. INJURIES.dbf

1. ACCIDENT.dbf- stores information specific to each accident in the study. The information stored includes:

a. Accident Identification Information
b. Aircraft Identification Information
c. Aircraft Damage & Accident Severity Summary
d. Injury Severity Summary
e. Accident Type/Phase of Operation
f. Crash Environment: Kinematics Information
g. Crash Environment: Environmental Conditions
h. Aircraft Flotation Equipment & Performance

2. OCCUPANT.dbf- stores information about each occupant's relationship to and interaction with the aircraft involved in the accident. The information stored includes:

a. Occupant Identification Information
b. Occupant Injury Degree
c. Occupant/Aircraft Interaction
d. Occupant Egress Information
e. Personal Flotation Equipment and Performance

3. INJURY.dbf- stores information on all injuries sustained by each occupant. This includes injury type location, severity, cause, and the injury's relationship to impact. The information stored includes:

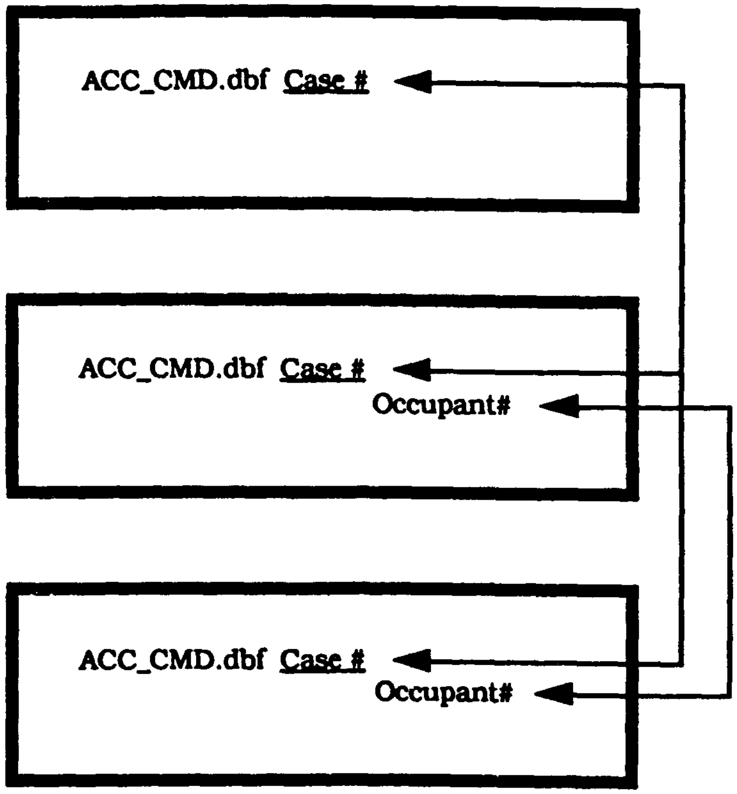
a. Occupant Identification Information
b. Injury Identification Information

Relationship Between Files

1. Accidents to Occupants- This is a one-to-many relationship. For each accident, there exist one or more occupants. These two files are linked by the unique case number assigned to each accident.

2. Occupants to Injuries- This is a one-to-many relationship. For each occupant in a particular accident, there exists none or more injuries. These two files are linked by a combination of the case number and the unique occupant number assigned to each occupant in an accident.

The following diagram shows this relationship.



Database Inputs and Outputs
All pertinent data from the accident reconstruction forms were input into these three files. Raw data was entered into the database wherever possible, and new codes were developed for areas where they were not previously defined (e.g. Flotation Information).

Reports and database queries were designed based on the categorization requirements.

Data Dictionary
A data dictionary detailing all the information was stored in the database. From this information, potential reports and queries can be requested. The structure for the database, data dictionary, and field codes for the three database files (accident.dbf, occupant.dbf, and injuries.dbf) are described in the following pages.

Field	Name	Type	Width	Dec	Index?	Range	Default
1	CASE_NO.	N	3	0	Y	1 to 999 Cases	Next Case#
2	LOCATION	C	40	0	N	40 Descriptive Characters	
3	DATE	C	8	0	N	MM/DD/YY	00/00/00
4	TIME	C	5	0	N	HH:MM on 24-hr clock	99:99
5	SOURCE	C	20	0	N	20 Descriptive Characters	
6	REG_NO	C	8	0	N	8 Descriptive Characters, N#######	
7	MFG	C	20	0	N	20 Descriptive Characters	
8	MODEL	C	20	0	N	20 Descriptive Characters	
9	WEIGHT	N	6	0	N	0 to 999,999 lbs	0
10	SEATS	N	3	0	N	1 to 999 seats	0
11	RECOVERED	C	1	0	N	Y,N,U	
12	DAMAGE	C	1	0	N	D,S,M,N,U	
13	FIRE	C	1	0	N	N,P,I,G,U	
14	SURVIVABLE	C	1	0	N	S,P,N,U	
15	ON_BOARD	N	3	0	N	1 to 999 persons on board	0
16	FATAL	N	3	0	N	0 to 999 persons with fatal injuries	0
17	SERIOUS	N	3	0	N	0 to 999 persons with serious injuries	0
18	MINOR	N	3	0	N	0 to 999 persons with minor injuries	0
19	NONE	N	3	0	N	0 to 999 persons with no injuries	0
20	ACC_TYPE_A	N	2	0	N	0 to 42, see Accident Type Codes	0
21	ACC_TYPE_B	N	2	0	N	0 to 42, see Accident Type Codes	0
22	ACC_TYPE_C	N	2	0	N	0 to 42, see Accident Type Codes	0
23	ACC_TYPE_D	N	2	0	N	0 to 42, see Accident Type Codes	0
24	ACC_TYPE_E	N	2	0	N	0 to 42, see Accident Type Codes	0
25	VERTICAL	N	6	1	N	-999.9 to 9999.9 ft/s (-999.9 if unk)	-999.9
26	LONGITUD	N	6	1	N	-999.9 to 9999.9 ft/s (-999.9 if unk)	-999.9
27	LATERAL	N	6	1	N	-999.9 to 9999.9 ft/s (-999.9 if unk)	-999.9
28	RESULTANT	N	6	1	N	-999.9 to 9999.9 ft/s (-999.9 if unk)	-999.9
29	RES_ANGLE	N	6	1	N	-360.0 to +360.0 degrees (-999.9 if unk)	-999.9
30	ROLL	N	6	1	N	-180.0 to +180.0 degrees (-999.9 if unk)	-999.9
31	PITCH	N	6	1	N	-180.0 to +180.0 degrees (-999.9 if unk)	-999.9
32	YAW	N	6	1	N	-180.0 to +180.0 degrees (-999.9 if unk)	-999.9
33	TERRAIN	C	1	0	N	A,B,C,D,E,F,G,H,I,J,K,L,M, P,R,S,Y,Z	K = Water
34	WATER_TYPE	C	1	0	N	F,S,O,U	
35	SEA_STATE	N	2	0	N	-1 to 99	-1

Field	Name	Type	Width	Dec	Index?	Range	Default
36	WIND_SPEED	N	3	0	N	-1 to 999 knots (use -1 if unknown)	-1
37	WIND_GUST	N	3	0	N	-1 to 999 knots (use -1 if unknown)	-1
38	WIND_DIR	N	3	0	N	-1 to 360 degrees (use -1 if unknown)	-1
39	WEATHER	C	1	0	N	V,I,U	
40	WATER_TEMP	N	3	0	N	-99 to 999 deg F, (use -99 if unknown)	-99
41	AIR_TEMP	N	3	0	N	-99 to 999 deg F, (use -99 if unknown)	-99
42	LAND_GEAR	C	2	0	N	SK,WN,WU,WD,OT,UK	
43	FL_INSTALL	C	1	0	N	Y,N,U	
44	FL_TYPE	C	10	0	N	10 Descriptive Characters	
45	FL_LOC	C	1	0	N	S,F,U,O,X	
46	FL_ARMED	C	1	0	N	Y,N,U,X	
47	FL_ACT_HOW	C	1	0	N	M,A,N,U,X	
48	FL_INF_WHN	C	1	0	N	B,P,A,U,X	
49	FL_SURVIVE	C	1	0	N	Y,N,U,X	
50	AID_EGRESS	C	1	0	N	Y,N,U,X	
51	AID_SURV	C	1	0	N	Y,N,U,X	
52	TIME_UP	N	3	0	N	-1 to 999 minutes, (use -1 if unknown)	-1
53	TIME_AFLT	N	3	0	N	-1 to 999 minutes, (use -1 if unknown)	-1
54	OVERTURN	C	1	0	N	I,A,W,D,F,X,N,O,U	

Accident.dbf Field Codes

The fields in the Accident.dbf database file use codes. The following describes these fields and their appropriate codes. Where character codes are descriptive, the appropriate letters are underlined in the descriptions. The field number is also indicated first in bold.

1 Case Number - The number assigned to the accident in question.

2 Location - The location of the accident. Usually the city and state in which the accident occurred, the closest city and state to the accident for cases offshore, or some other identifier (e.g. oil rig).

3 Date - Date of occurrence, MM/DD/YY.

4 Time - Local time of day when accident occurred, HH:MM, on 24 hour clock.

5 Source - Accident report source of data (e.g. NTSB).

6 Registration Number - The official FAA licensed registration number or tail number assigned to the aircraft.

7 Manufacturer - The manufacturer of the aircraft.

8 Model - The manufacturer's aircraft model number or U.S. Army designation.

9 Weight - The aircraft design gross weight (DGW) in pounds.

10 Seats - The total number of occupant seats on the aircraft as configured at the time of the accident.

11 Recovered - Was the aircraft recovered?

Code	Recovered?
Y -	Yes
N -	No
U -	Unknown

12 Damage - Indicated the extent of the damage to the aircraft. The following indicates the codes assigned to the damage sustained.

Code	Damage
D -	Destroyed
S -	Substantial
M -	Minor
N -	None
U -	Unknown

13 Fire - Indicates the presence of a fire, and if so, was it a factor?

- N - No, fire was not a factor
- P - Yes, fire was a factor, Postcrash fire
- I - Yes, fire was a factor, Inflight fire
- G - Yes, fire was a factor, Ground fire, not associated with the accident
- U - Unknown

14 Survivable - Indicates the degree of occupant survivability in the accident.

Survivable - the acceleration environment was within the limits of human tolerance, and a sufficient occupiable volume remained for properly restrained (lapbelt and shoulder harness) occupants, with the effects of fire not considered.

Partially Survivable - Some portion of the cockpit or cabin met the definition of survivable.

Nonsurvivable - No portion of the cockpit or cabin met the definition of survivable.

The codes indicating levels of survivability are:

- S - Survivable
- P - Partially Survivable
- N - Nonsurvivable
- U - Unknown

15 Number Onboard - The total number of occupants on the aircraft.

16 Number of Fatalities - The total number of fatalities that occurred during the mishap.

17 Number of Serious Injuries - The total number of occupants that received serious injuries during the mishap.

18 Number of Minor Injuries - The total number of occupants that received minor injuries during the mishap.

19 Number of Uninjured Occupants - The total number of occupants that remained uninjured during the mishap.

20-24

Accident Type Codes - The type of event as defined by the following 42 codes derived from the NTSB. There are five fields allocated for describing the accident type: A,B,C,D,E. The 42 codes are listed below:

Code	Type of Accident
1	Abrupt maneuver
2	Altitude deviation, uncontrolled
3	Airframe/component/system fail./malfunction
4	Ditching
5	Dragged wing, rotor, pod, or float
6	Fire/explosion
7	Fire
8	Forced landing
9	Gear collapsed
10	Main gear collapsed
11	Nose gear collapsed
12	Complete gear collapsed
13	Gear not extended
14	Hard landing
15	In flight collision with object
16	In flight collision with terrain
17	In flight encounter with weather
18	Loss of control - in flight
19	Loss of control - on ground
20	Midair collision
21	Near collision between aircraft
22	Nose down
23	Nose over
24	On ground collision with object
25	On ground collision with terrain
26	On ground encounter with weather
27	Overrun
28	Loss of power
29	Loss of power (total) - mech fail/malfunction
30	Loss of power (partial)- mech fail/malfunction
31	Loss of power (total) - non-mechanical
32	Loss of power (partial) - non-mechanical
33	Propeller blast or jet exhaust/suction
34	Propeller/rotor contact
35	Roll over
36	Undershoot
37	Undetermined
38	Vortex turbulence encountered
39	Missing aircraft
40	Miscellaneous/other
41	Not reported
42	Other

25-29

Velocity Vectors:

Velocity vectors were calculated in the aircraft coordinate system. Longitudinal, Vertical, and Lateral Velocities which correspond to the mutually perpendicular aircraft coordinates were recorded in ft/s. The resultant velocity vector was also calculated.

30-32

Impact Attitudes:

30 Roll - roll is the aircraft's degree of rotation measured from level about its' longitudinal X-axis. It ranges from (+)90 degrees to (-)90 degrees. Right roll is designated as positive and left roll is negative.

31 Pitch - pitch is the aircraft's degree of rotation measured from level about its' lateral Y-axis. It is measured as the angle between the aircraft's longitudinal X-axis and its flight path. Pitch can range from (+)90 degrees to (-)90 degrees. Nose-up is designated as positive and nose-down is negative.

32 Yaw - yaw is the aircraft's degree of rotation of its' nose about its' vertical Z-axis. It ranges from (+)180 degrees to (-)180 degrees and is measured from the flight path. Right yaw is designated as positive and left yaw is negative.

33 Terrain - The type of terrain encountered upon impact. The following table indicates the eighteen possibilities. For this study, all impacts were water (Code K) impacts.

Code	Terrain
A	Mountainous
B	Hilly
C	Rolling
D	Leel, flat
E	Frozen
F	Rocky
G	Sandy
H	Dense with trees
I	City Area
J	Plowed
K	Water
L	Sloped
M	now
P	Paved
R	Off-shore Rig
S	Soft
Y	Other
Z	Unknown

34 Type of Water - type of water encountered upon impact.

- F - Fresh
- S - Salt
- O - Other
- U - Unknown

35 Sea State - classification of water surface by wave height. Enter numerical wave height (ft). (-1 = unknown)

36 Wind Speed - the speed of the wind in knots, as reported by the accident data.

37 Wind Gust - the speed of wind gusts in knots, as reported by the accident data.

38 Wind Direction - the wind direction in degrees, as reported by the accident data.

39 Weather - indicates basic prevailing weather conditions for aircraft operations:

- V - Visual Meteorological Conditions (VMC)
- I - Instrument Meteorological Conditions (IMC)
- U - Unknown

40 Water Temperature - indicated in degrees Fahrenheit.

41 Air Temperature - indicated in degrees Fahrenheit.

42 Landing Gear - Indicates the landing gear type and its status upon impact. Codes are:

- SK - Skid
- WN - Wheel, Non-retractable
- WU - Wheel, Retractable, Up
- WD - Wheel, Retractable, Down
- OT - Other
- UN - Unknown

43 Floats Installed? - Indicates the presence of floats on the aircraft. Codes are:

- Y - Yes
- N - No
- U - Unknown

44 Float Type - Describes the type of float installed on the aircraft. Codes are listed below:

- F - Fixed
- E - Emergency
- O - Other
- N - None
- U - Unknown

45 Location on Aircraft - Documents the location of floats on the aircraft. Codes are:

S - On Skids
F - On Fuselage
O - Other mounting configuration
U - Unknown
X - Not Applicable, X, for no floats on aircraft

46 Floats Armed? - Indicates whether or not the floats were armed. Codes are:

Y - Yes
N - No
U - Unknown
X - Not Applicable, X, for no floats on aircraft

47 Floats Activated How?

M - Manually Activated
A - Automatically Activated
N - Not Activated
U - Unknown
X - Not Applicable, X, for no floats on aircraft

48 Floats Activated When?

B - Before or Pre-Impact
P - Post-Impact
A - At Impact
U - Unknown
X - Not Applicable, X, for floats never activated or floats not on aircraft

49 Did Floats Survive Impact? Codes are as follows:

Y - Yes
N - No
U - Unknown
X - Not Applicable, X, for no floats on aircraft

50 Aided Occupant Egress? - Indicates in general, if the floats assisted in the occupants' egress of the ditched aircraft.

Y - Yes
N - No
U - Unknown
X - Not Applicable, X, could not aid egress because there were no floats on aircraft

51 Aided Survivability? - Indicates in general, if the floats increased the occupants' chances of survival and reduced the risk of injury.

Y - Yes
N - No
U - Unknown
X - Not Applicable, X, for no floats on aircraft

52 Time Aircraft Remained Upright - Indicates the time in minutes, if available, that the aircraft remained upright in the water. This duration was rounded to the nearest 5 minutes for values over 5 minutes, otherwise the time was recorded to the nearest minute. The value -1 was recorded if the time upright was unknown.

53 Time Aircraft Remained Afloat - Indicates how long the aircraft remained afloat, if known, for in minutes. This duration was rounded to the nearest 5 minutes for values over 5 minutes, otherwise the time was recorded to the nearest minute. The value -1 was recorded if the time afloat was unknown.

54 Cause of Overturning - Indicates the most probable cause of overturning the aircraft. Codes are as follows:

I - Intentional
A - Impact Attitude
W - Weather (rough seas or high winds)
D - Uneven Float Deployment
F - Float Problems other than uneven float deployment.
X - Not Applicable, X, Did Not Overturn
N - Not Equipped with Floats
O - Other
U - Unknown

Page No. 1 Data Dictionary for Occupant.dbf File
03/19/91

Field	Name	Type	Length	Dec	Index?	Range	Default
1	CASE_NO	N	3	0	Y	1 to 999 Cases	Next Case#
2	OCC_NO	N	3	0	Y	1 to 999 Occupants	Next Occ #
3	POSITION	C	2	0	N	FP,FC,FS,MP,MC,MS,AP ,AC,AS,OT,UK	
4	INJURY_DEG	C	1	0	N	F,S,M,N,U	
5	RESTRAINT	C	1	0	N	0,2,3,4,5,U	
6	EXIT_LOC	C	2	0	N	FP,FC,FS,MP,MC,MS,AP ,AC,AS,NO,OT,UK	
7	EXIT_TYPE	C	1	0	N	D,W,H,F,O,U,X	
8	AC_STATUS	C	3	0	N	FLO,PSB,SIN,ROB,UNK,OTH	
9	PERS_FLOAT	C	1	0	N	Y,N,U	
10	USED	C	1	0	N	Y,N,U,X	
11	N_INF_VEST	C	1	0	N	Y,N,U,X	
12	INF_VEST	C	1	0	N	Y,N,U,X	
13	LIFERAFT	C	1	0	N	Y,N,U,X	
14	SEAT_CUSH	C	1	0	N	Y,N,U,X	
15	WORKED	C	1	0	N	Y,N,U,X	
16	TIW	N	3	0	N	-1 to 999 minutes	-1

Occupant.dbf Field Codes

The fields in the Occupant.dbf database file use codes. The following describes these fields and their appropriate codes. Where character codes are descriptive, the appropriate letters are underlined in the descriptions. The field number is also indicated first in bold.

1 Case Number - The number assigned, for record keeping purposes, to each accident report obtained for this study.

2 Occupant Number - The number used to identify the occupant throughout the reconstruction form. Also, the role of the occupant is listed as pilot or passenger and the name is given if available.

3 Position in A/C - For categorization and analysis purposes, the location of each occupant is also assigned a seating position code corresponding to the following table. The table depicts nine (9) seating positions from a top view of the aircraft.

Seating Position Codes

	Port	Center	Starboard
Front	FP	FC	FS
Middle	MP	MC	MS
Aft	AP	AC	AS

Codes are as follows:

FP - Front, Port
FC - Front, Center
FS - Front, Starboard
MP - Middle, Port
MC - Middle, Center
MS - Middle, Starboard
AP - Aft, Port
AC - Aft, Center
AS - Aft, Starboard
OT - Other
UK - Unknown

4 Injury Degree - The overall degree of injury sustained by the occupant in the accident is indicated in the following codes:

Code Overall Injury Degree
F - Fatal
S - Serious
M - Minor
N - None
U - Unknown

5 Restraint - The type of restraint worn by the occupant at time of impact is listed as 2-point, 3-point, 4-point, 5-point, none, or unknown. Codes are:

0 - None used, 0
2 - 2-point
3 - 3-point
4 - 4-point
5 - 5-point
U - Unknown

6 Location of Exit Used - The location of each exit an occupant used in exiting the aircraft is assigned a code corresponding to the following table. The table depicts nine (9) exit locations from a top view of the aircraft.

Exit Location Codes

	Port	Center	Starboard
Front	FP	FC	FS
Middle	MP	MC	MS
Aft	AP	AC	AS

Codes are as follows:

FP - Front, Port
FC - Front, Center
FS - Front, Starboard
MP - Middle, Port
MC - Middle, Center
MS - Middle, Starboard
AP - Aft, Port
AC - Aft, Center
AS - Aft, Starboard
OT - Other
NO - None, for no exit used
UK - Unknown

7 Exit Type - The type of exit used is classified by the following codes:

D - Door
W - Window
H - Overhead Hatch
F - Fuselage Split
U - Unknown
X - Not Applicable, X, no exit used because occupant never exited aircraft

8 Aircraft Status - Indicates the flotation status of the aircraft during occupant egress. The codes are:

FLO - Floating
PSB - Partially Submerged
SIN - Sinking
ROB - Resting On Bottom
UNK - Unknown
OTH - Other, occupant never egressed or another condition existed

9 Personal Flotation Available? - Indicates whether or not personal flotation was available.

Y - Yes
N - No
U - Unknown

10 Used? - Indicates whether or not personal flotation was used.

Y Yes
N No
U Unknown
X Not Applicable, X, no personal flotation was used because none was available

11 Non-Inflatable Vest Used? - Indicates whether or not a non-inflatable life vest was used by the occupant for flotation.

Y Yes
N No
U Unknown
X Not Applicable, X, no personal flotation used because none was available

12 Inflatable Vest Used? - Indicates whether or not an inflatable life vest was used by the occupant for flotation.

Y Yes
N No
U Unknown
X Not Applicable, X, no personal flotation used because none was available

13 Liferaft Used? - Indicates whether or not a liferaft was used by the occupant for flotation.

Y Yes
N No
U Unknown
X Not Applicable, X, no personal flotation used because none was available

14 Seat Cushion Used? - Indicates whether or not a seat cushion was used by the occupant for flotation.

Y Yes
N No
U Unknown
X Not Applicable, X, no personal flotation used because none was available

15 Worked? - In general, indicates whether or not personal flotation functioned satisfactorily.

Y Yes
N No
U Unknown
X Not Applicable, X, for no personal flotation was used and therefore its function was irrelevant (e.g. for impact fatalities, personal floatation function is not applicable.)

16 Time in Water (TIW) - This is the recorded time, if available, that the occupant is involved in the ditching environment, from moment of impact to rescue. This is recorded to the nearest five minute interval. Periods of time below a total of five minutes in the ditching environment are recorded to the nearest minute. The value -1 was recorded when the time in the water was unknown.

Page No. 1 Data Dictionary for Injury.dbf File
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Field	Name	Type	Length	Dec	Index?	Range	Default
1	CASE_NO	N	3	0	Y	1 to 999 Cases	Next Case#
2	OCC_NO	N	3	0	Y	1 to 999 Occupants	Next Occ #
3	TYPE	C	2	0	N	01 to 99 NTSB Codes	
4	LOCATION	C	2	0	N	01 to 99 NTSB Codes	
5	SEVERITY	C	2	0	N	01 to 88 NTSB Codes	
6	CAUSE	C	2	0	N	01 to 99 NTSB Codes	
7	INJ_IMPACT	C	1	0	N	I,P,U	

Injury.dbf Field Codes

The fields in the Injury.dbf database file use codes. The following describes these fields and their appropriate codes. Where character codes are descriptive, the appropriate letters are underlined in the descriptions. The field number is also indicated first in bold.

1 Case Number - The number assigned, for record keeping purposes, to each accident report obtained for this study.

2 Occupant Number - The number used to identify the occupant throughout the reconstruction form. Also, the role of the occupant is listed as pilot or passenger and the name is given if available.

3 Injury Type - The specific type of the particular injury (from NTSB Form 6120.4 Supplement K (1-84), Lesion - C) is listed as:

01 Laceration
02 Contusion
03 Abrasion
04 Fracture
05 Concussion
06 Avulsion
07 Rupture
08 Sprain
09 Dislocation
10 Crush
11 Amputation
12 Burn
13 Fracture and dislocation
14 Severance (Transection)
15 Strain
16 Detachment (Separation)
17 Perforation (Puncture)
18 Suffocation
88 Injured unknown lesion
99 Other

4 Injury Location - The bodily location of the particular injury (from NTSB Form 6120.4 Supplement K (1-84), Body Region - A) is listed as:

01 Head (Skull, scalp, ears)
02 Face (Forehead, nose, eyes, mouth)
03 Neck (Cervical spine, C1-C7)
04 Shoulder (Clavicle, scapula, joint)
05 Upper limb (Whole arm)
06 Arm (Upper)
07 Elbow
08 Forearm
09 Wrist
10 Hand-fingers
11 Chest (Anterior and posterior ribs)
12 Abdomen (Diaphragm and below)
13 Back (Thoracic spine T1-T12)
14 Back (Lumbar L1-L5)
15 Pelvis-hip
16 Lower limb (Whole leg)
17 Thigh (Femur)
18 Knee
19 Leg (Below knee)
20 Ankle
21 Foot-toes
22 Whole body
88 Injured, unknown region
99 Other

5 Injury Severity - The general severity of the particular injury (from NTSB Form 6120.4 Supplement K (1-84), Abbreviated Injury Scale - E) is listed as:

00 Not injured
01 Minor injury
02 Moderate Injury
03 Serious Injury (Not life-threatening)
04 Severe Injury (Life-threatening survival probable)
05 Critical injury (Survival uncertain)
06 Maximum (Untreatable - fatal)
07 Injured (Unknown severity)
88 Unknown if injured

6 Injury Cause - The cause or source of the particular injury (from NTSB Form 6120.4 Supplement K (1-84), Injury Source List - F) is listed as:

01 Windshield
02 Windshield frame
03 Window
04 Window frame
05 Instrument panel
06 Side console
07 Center console
08 Control stick/cyclic stick
09 Collective
10 Control yoke/column
11 Throttle quadrant/levers
12 Rudder pedals
13 Ceiling
14 Sidewall
15 Floor
16 Fuselage framing/structure
17 Table
18 Seat
19 Seatback tray
20 Restraints-seatbelt/tiedown
21 Restraints-shoulder harness
22 Unsecured item(s) in cockpit
23 Unsecured item(s) in cabin
24 Other occupants
25 Ground/runway
26 Unsecured seat(s)
27 Outside object(s) entering aircraft
28 Galley item(s)
29 Food/beverage item(s)
30 Other interior objects
31 Other exterior objects
32 Evacuation slide/slide raft
33 Escape rope/tape
34 Escape inertia device
35 Ejected from aircraft
36 Propeller/rotor blades
37 Exterior aircraft surface
38 Engine
39 Wheel/tires
40 Ground vehicle
41 Toxic/noxious/irritant fumes
42 Fire/radiant heat
43 Flying glass
44 Door/hatches
45 Acceleration forces
46 Exposure
47 Glare shield
48 Eyeglasses
49 Inhalation of water
88 Unknown
99 Other

7 Injury-Impact Relationship - Indicates the causative relationship between the injury sustained and the impact. Codes are as follows:

I - Impact Injury
P - Post-Impact Injury
U - Unknown relationship between injury & impact

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